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RATIONALE

GUIDE FOR EVALUATING 12 INCH SUBSTANTIAL DIVIDING WALLS (SDWs) TO PROVIDE PROTECTION FROM REMOTE OPERATION

VOLUME II

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13. ABSTRACT *(Maximum 200 words)*

This report provides installations with procedures to relate Net Explosive Weights (NEWs) to combinations of intervening 12-inch Substantial Dividing Walls (SDWs) to provide protection to personnel from remote operations where an accidental detonation is the hazard. Protection to be provided is IAW DoD and Army policy: 2.3 psi maximum overpressure exposure and no hazardous fragments. The report consists of two Volumes. Volume I is a "how to" guide for installation use; Volume II is the rationale (calculations, etc) behind the Volume I. Protection from thermal effects from flash fires, deflagrations, etc. is not addressed in the Guide.

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1.0 INTRODUCTION

1.1 BACKGROUND

In recent years, the Department of Defense Explosive Safety Board (DDESB) introduced increased protection requirements for personnel exposed to remotely controlled operations. One of the requirements is limiting exposure of personnel to blast pressures not in excess of 2.3 psi. This requirement has forced some Army installations to relocate operators to bays sufficiently removed from the donor bay to comply with the new regulation. This requirement has for the most part imposed operational constraints since intervening bays can be occupied only when the remote operation is not in progress.

As a result of the above, the US Army Technical Center of Explosive Safety saw a need for relating Net Explosive Weight (NEW) to combinations of intervening 12-inch SDWs.

1.2 OBJECTIVE

The objective of this report is to form a basis for development of a guide that allows installation personnel to assess existing munition facilities for conformance with present safety requirements. It is not the intent that this guide be used for the design and construction of new munition facilities, but rather for the evaluation of existing facilities constructed of 12-inch Substantial Dividing Walls (SDWs). Methods for upgrading walls to resist higher blast loadings is provided.

1.3 SCOPE

a. Determine the degree of personnel fragment protection provided by combinations of 12" SDWs interposed between operators and a donor source.

b. Guidance on field expedient methods to increase the strength of 12-inch SDWs to resist the effects of detonations greater than 15 pounds.

c. Information on any portable shelter which may have application in providing blast protection to remote operators.

d. Guidance on use of methods to protect operators from high angle structural/equipment debris.

e. Guidance on methods to protect operators from spillover pressure.

1.4 FORMAT OF GUIDE

This volume addresses rationale for the development of data and procedures presented in Volume I. As directed, Volume I is developed as a "stand-alone" document. Therefore some duplication between the two volumes was unavoidable.

1.5 REFERENCES

a. DoD 6055.9-STD, July 1984, Ammunition and Explosives Safety Standards.

b. AR 385-64, 22 May 1987, Ammunition and Explosives Safety Standards.

c. Draft TM5-1300, Structures to Resist the Effects of Accidental Explosives.

d. WES Technical Report SL-88-22, "Spall Damage of Concrete Structures", June 1988.

e. NCEL Technical Memorandum M51-85-18, "Design Criteria for Substantial Dividing Wall", November 1985.

f. NCEL, Computer Program "SHOCK", January 1988.

g. NCEL, Technical Report R 823, Explosive Tests of Blast Cell, Naval Torpedo Station, Bangor Annex", May 1975.

2.0 SAFETY CRITERIA

2.1 General

Twelve-inch reinforced concrete walls, commonly known as Substantial Dividing Walls, have been constructed for many years within DoD munitions facilities to limit blast effects from accidental explosions. Such walls are a special category of "Dividing Walls" as defined by DoD explosive safety standards. When used as shields to protect personnel during remote operation, specific explosive limits for these walls are defined as follows:

Wall Thickness	NEW
12"	15 Lb.
30"	50 Lbs
36"	70 Lb.

These levels were established years ago by U.S. Army Material Command (AMC) and although long thought to provide complete protection, are now known to only provide protection for the operator on the other side of the wall from primary fragments and wall spall.

With the more stringent safety criteria now in place, Department of Defense Explosive Safety Board (DDESB) is presently requiring installations to comply with the present requirements to assure maximum protection to facility operators.

2.2 PROTECTION OF OPERATORS

Safety criteria clearly require that personnel must not be exposed to overpressures greater that 2.3 psi, must not be exposed to hazardous fragments (primary or secondary), and must be afforded Category I protection in accordance with requirements of TM5-1300. US Army Technical Center of Explosive Safety has in recent months provided installations with a method for determining the 2.3 psi boundary arc from the front, sides, and the back of a three walled cubicles without roof. For ready access, this method has been made an integral part of Volume I .

3.0 SUBSTANTIAL DIVIDING WALLS (SDWs)

3.1 GENERAL

This report is based on the "standard" 12-inch reinforced concrete Substantial Dividing Walls: with #4 reinforcements each way each face and spaced at 12 inches on centers with the wall reinforcements anchored into the concrete floor slab. A typical cross-section of SDW is shown in Figure 3-1. Also, a typical configuration of SDW ammunition building is shown in Figures 3-2 & 3-3. Most buildings consist of two-wall or three-wall cubicles running down the longitudinal axis of the building. Two-wall cubicle buildings typically feature a series of lateral SDWs (cantilever walls). Three-wall cubicle buildings typically feature an additional SDW running longitudinally down the building, bisecting the lateral SDWs along the way.

3.2 DYNAMIC PROPERTIES OF SUBSTANTIAL DIVIDING WALLS

The dynamic properties of Substantial Dividing Walls presented in Table 3-1 thru 3-3 were generated using the computer program "CBARCS". The tabulated results are based on allowable wall rotation of 1-degree as required by TM5-1300 for walls with no shear reinforcements. In all cases 3,000 psi concrete compressive strength and 60,000 psi yield strength of reinforcement were assumed. For the heights selected (10 to 16 feet), the cantilever walls exhibit a very low ultimate resistance ranging from 1.73 psi for a 10' high wall to 0.68 psi for a 16' high wall. For walls fixed on two or three edges the ultimate resistance is, as expected, well above the cantilevered walls. This therefore suggests that wall upgrade by the addition of fixity condition at the free end will substantially increase the wall capacity.

3.3 BLAST CAPACITY OF SUBSTANTIAL DIVIDING WALLS

Blast capacity of different size SDWs were developed to provide the means in rapidly determining the adequacy of SDW in providing Category I protection at a desired standoff from a donor bay. Knowing the ultimate resistance and natural period of a specific wall, Pressure-Duration plots were generated using Figure 3-64 of TM5-1300 and are presented in Figures 3-4 thru 3-14. These plots are similar to P-I diagrams except that load duration was used in the abscissa to facilitate usage by installation personnel. Once the blast loadings are determined for a specific charge weight and a standoff, a point is plotted on the appropriate figure. The wall in question is considered adequate in providing personnel protection if the plotted point falls below the curve. On the other hand, if the point falls above the curve, then the wall is inadequate in providing the necessary protection. It is evident from the plotted data that wall heights and fixity conditions at the perimeter of the elements have a significant influence on the walls capacities.

3.4 SAND LAYER INCLUSION BEHIND SDW

An effective method in achieving greater wall resistance to blast loadings, is increasing the mass of the element. This results in a higher natural period of vibration of the element which affects the element response and its load carrying capacity. To determine the effects of sand layers behind walls fixed on 2-edges (i.e. attachment to floor and one other wall), several runs were made using the computer program "CBARCS". The results are plotted in Figures 3-15 thru 3-38. Three sand thicknesses were selected for this study, namely: 1.0', 2.5', and 5.0'. The results indicate increased load carrying capacity with increased sand thickness. Review of the plotted data show approximately 20 percent increase in load carrying capacity for each sand thickness considered. With 5 feet of sand the increase is 60 percent. The data presented in Figures 3-15 thru 3-38 is based on loose sand retained by a structural framing system. The use of sand bags is also an acceptable alternate providing the sand bags are restrained in place, and an adjustment is made to the thickness to account for voids between the sand bag units. A reasonable adjustment would be to increase the sand layer thickness by 15 percent (arbitrarily selected). Wall fixed on 3-edges (i.e. floor and two other walls) were not analyzed with sand mass because of their greater resistance to blast loadings. Also, these walls normally run down the building longitudinal axis dividing the building in half.

3.5 SUBSTANTIAL DIVIDING WALLS RESISTANCE TO FRAGMENTS

The accidental detonation in an explosive processing facility can result in the generation of many primary and /or secondary fragments. On contact with the 12-inch SDW, the fragment will either penetrate some distance into the structure and be stopped, or perforate completely through and emerge from the back face with some residual velocity and mass. Whether partial penetration or perforation occurs depends primarily on the weight of the fragment, it's initial velocity, and the element it is impacting. The effectiveness of reinforced concrete in resisting penetration by steel fragments is substantially less than a steel plate but greater than penetration into sand. When dealing with concrete elements consideration must also be given to perforation and spall thicknesses. For comparison purposes, Table 3-4 shows the penetration of a design fragment into the materials discussed above.

As directed in the scope, development of the guide is based on worst case munition accident scenario of an 8-inch artillery round. From TM5-855-1, Table 6-2, the design fragment weight (W_f) is 3.44 oz. Using TM5-1300 methodology, and a Gurney Energy constant of 9,100 ft/sec (Composition B explosives), an initial striking velocity of 4,450 ft/sec was calculated. Note that this velocity differs from the velocity of 3,780 ft/sec shown in TM5-855-1. It appears that the Gurney constant used in TM5-855-1 is that corresponding to TNT type of explosive (Gurney constant of 7,600 ft/sec). The calculated value of 4,450 ft/sec has been based on Composition B explosives. Note: TM43-0001-28 shows 8" artillery rounds to have explosive limits of 36.3# TNT or 38.8# of Composition B.

It is evident from Table 3-4 that a 12-inch SDW will resist the design fragment indicated above - the spall thickness of 11.7" is less than the wall thickness of 12". For a design fragment of greater mass or striking velocity, the wall may not provide the necessary protection if operators are positioned in the adjacent bay. Reevaluation must follow TM5-1300 methodology.

3.6 BREACHING OF 12-INCH SDW

Breaching was evaluated using WES Technical Report SL-88-22, reference d. The report summarizes the theories of spall, tests involving spall, and current prediction methods. In addition, improved prediction methods are provided. Figures 3.1 and 8.1 of the referenced report were used to generate Figure 3-40 and 3-41. These figures show regions of "no damage","spall", and "breach" as a function of standoff distance and NEW. Net Explosive Weight quantities were superimposed on the figures to assess damage levels at specified standoffs. For NEW of 150 Lb. bare charge, the SDW will be breached if the standoff distance is less than 3.6', and spall is avoided if the standoff distance greater than 14'. For NEW of 15 Lb. bare charge, breach occurs at a standoff distance of 0.44', and spall avoided if the standoff distance is greater than 1.7'. Since most facility bays are generally in the realm of 12 feet, the figures suggest that breach will not control the design since operator location will, in most probability, be dictated by overpressures including structural adequacy of the dividing wall to resist the blast loadings.

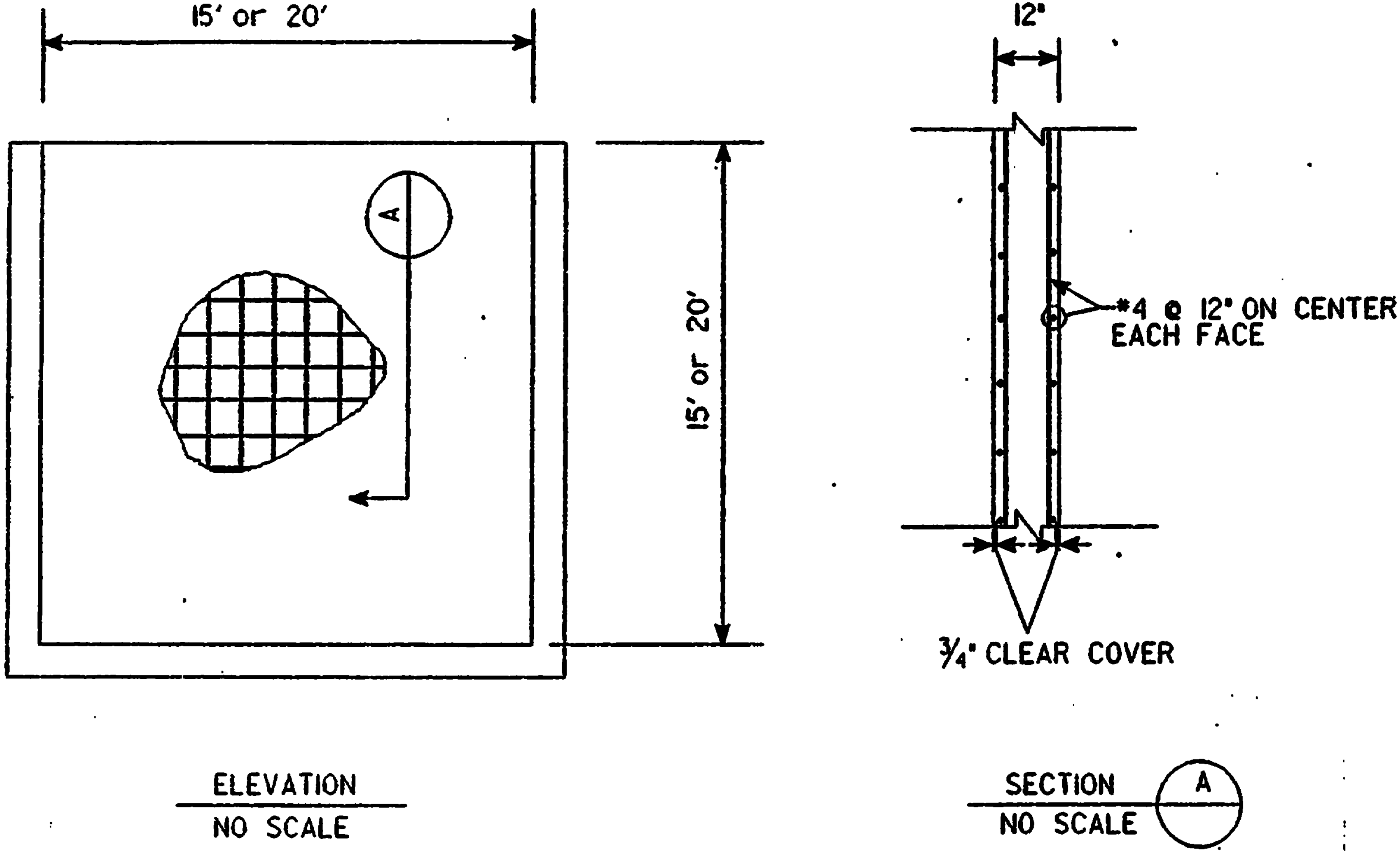
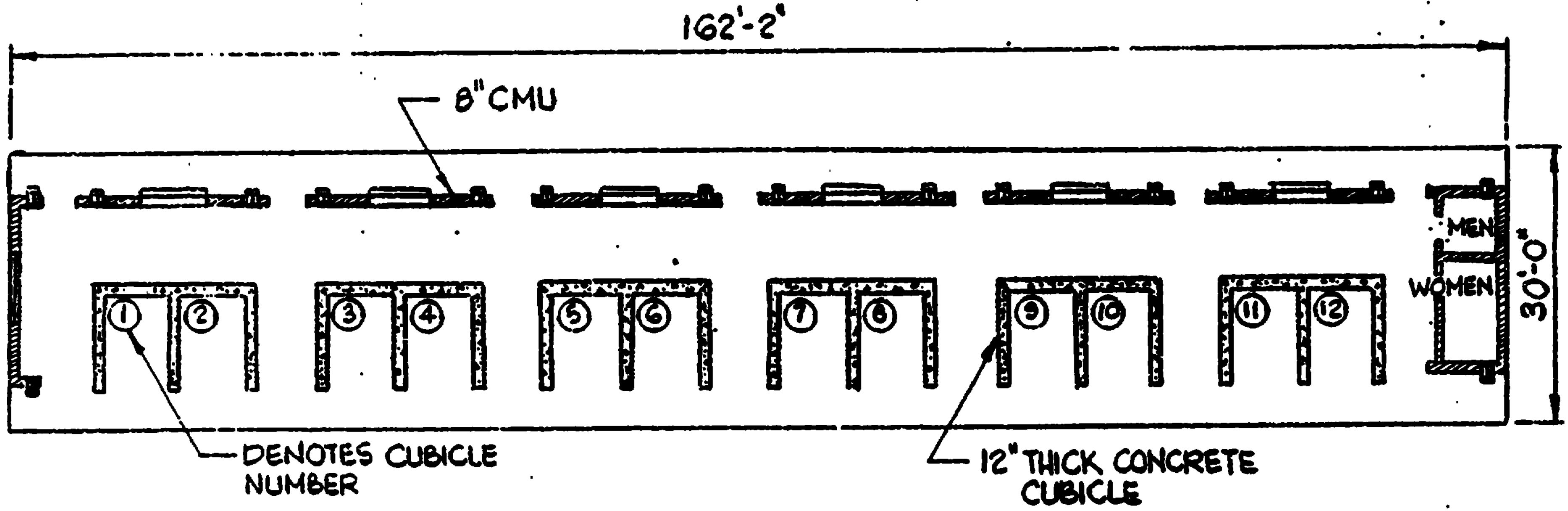


FIGURE 3-1 - Typical 12" Reinforced Concrete Dividing Wall



FLOOR PLAN

FIGURE 3-2 FLOOR PLAN

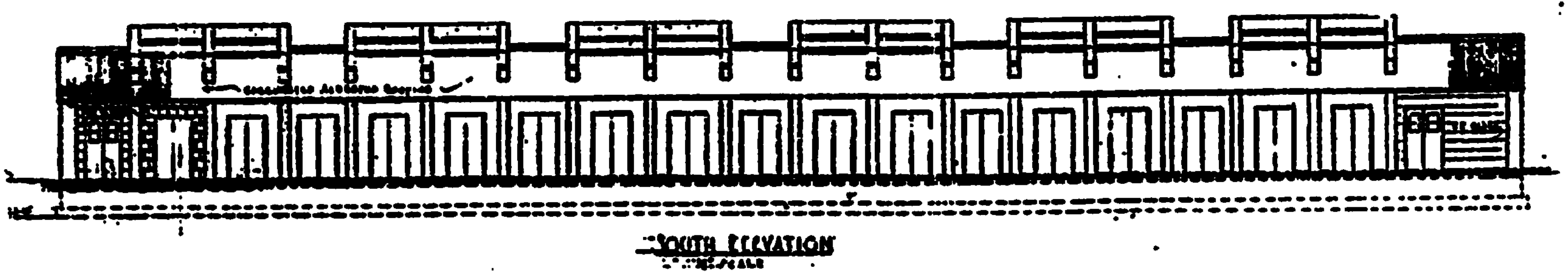


FIGURE 3-3 BUILDING ELEVATION

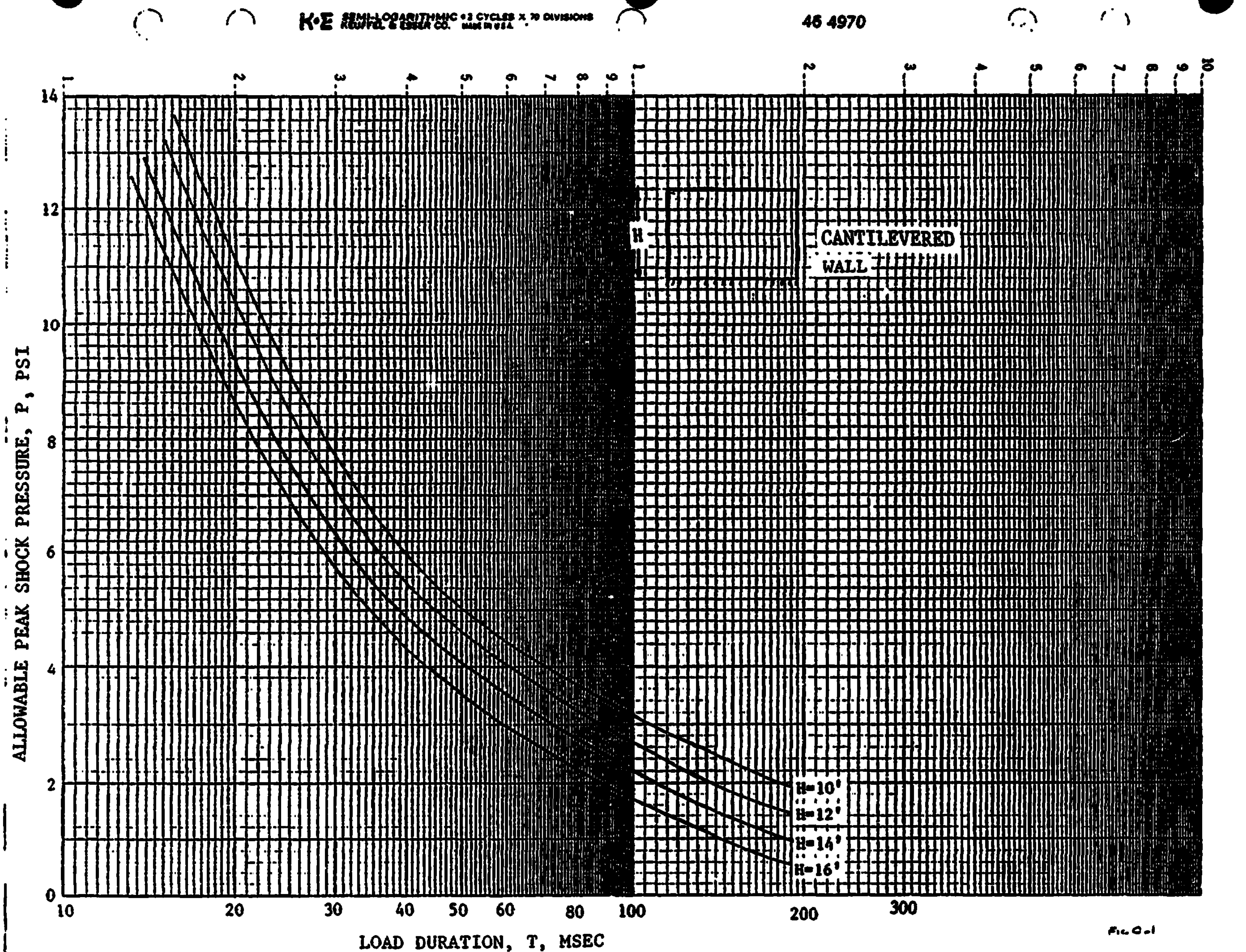


FIGURE 3-4 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION

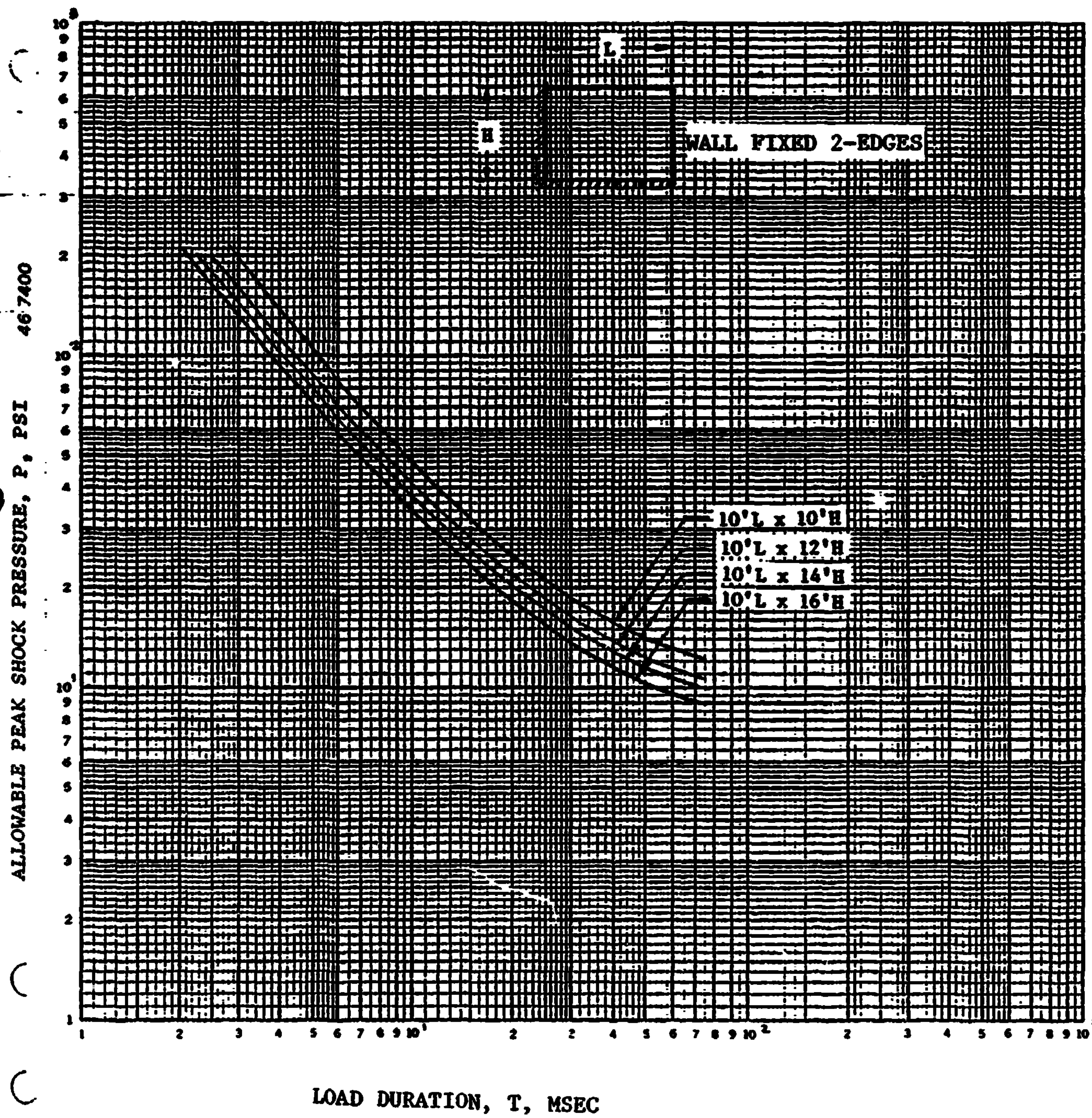
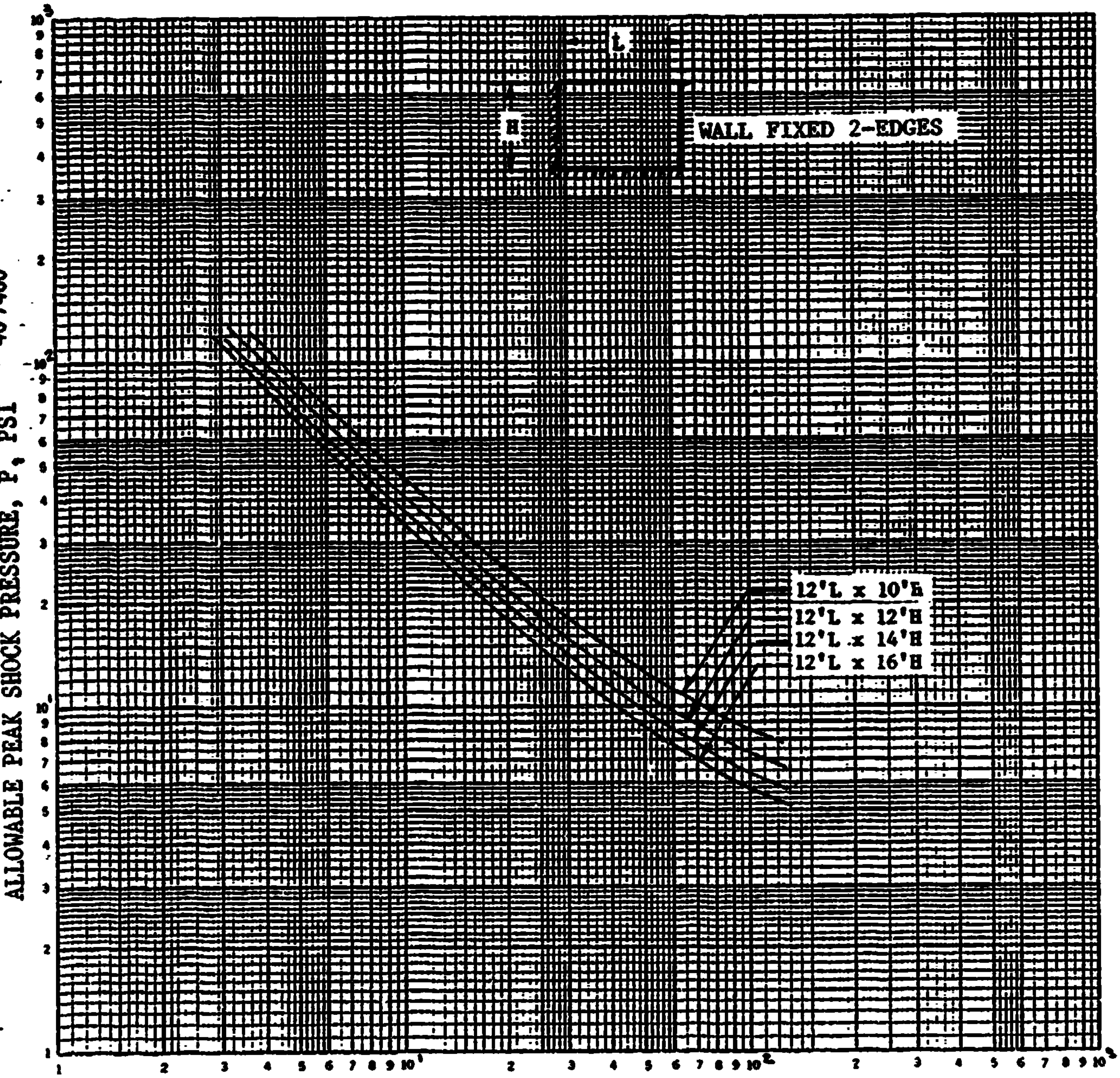


FIGURE 3-5 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION



LOAD DURATION, T, MSEC

FIGURE 3-6 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION

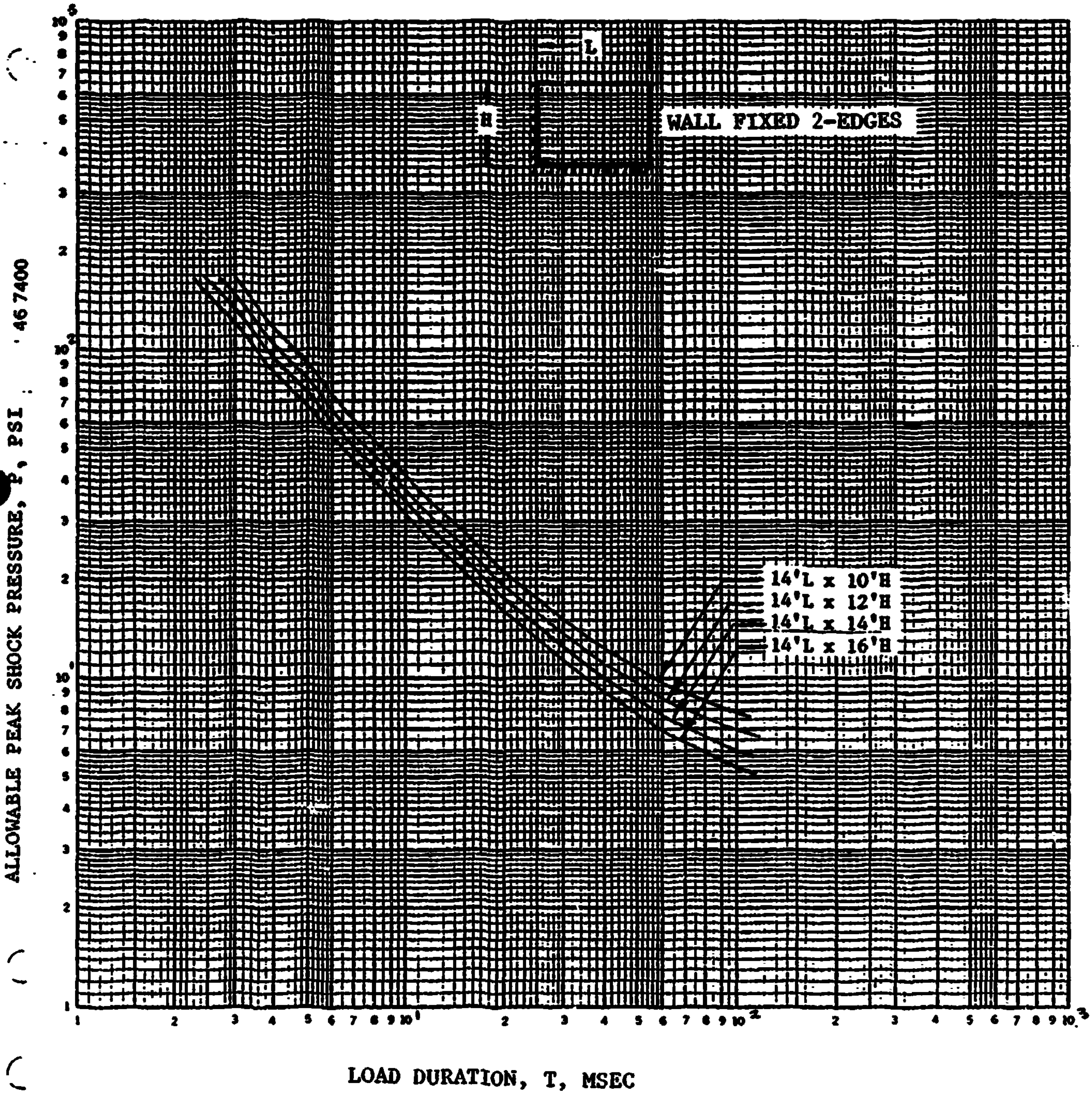


FIGURE 3-7 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION

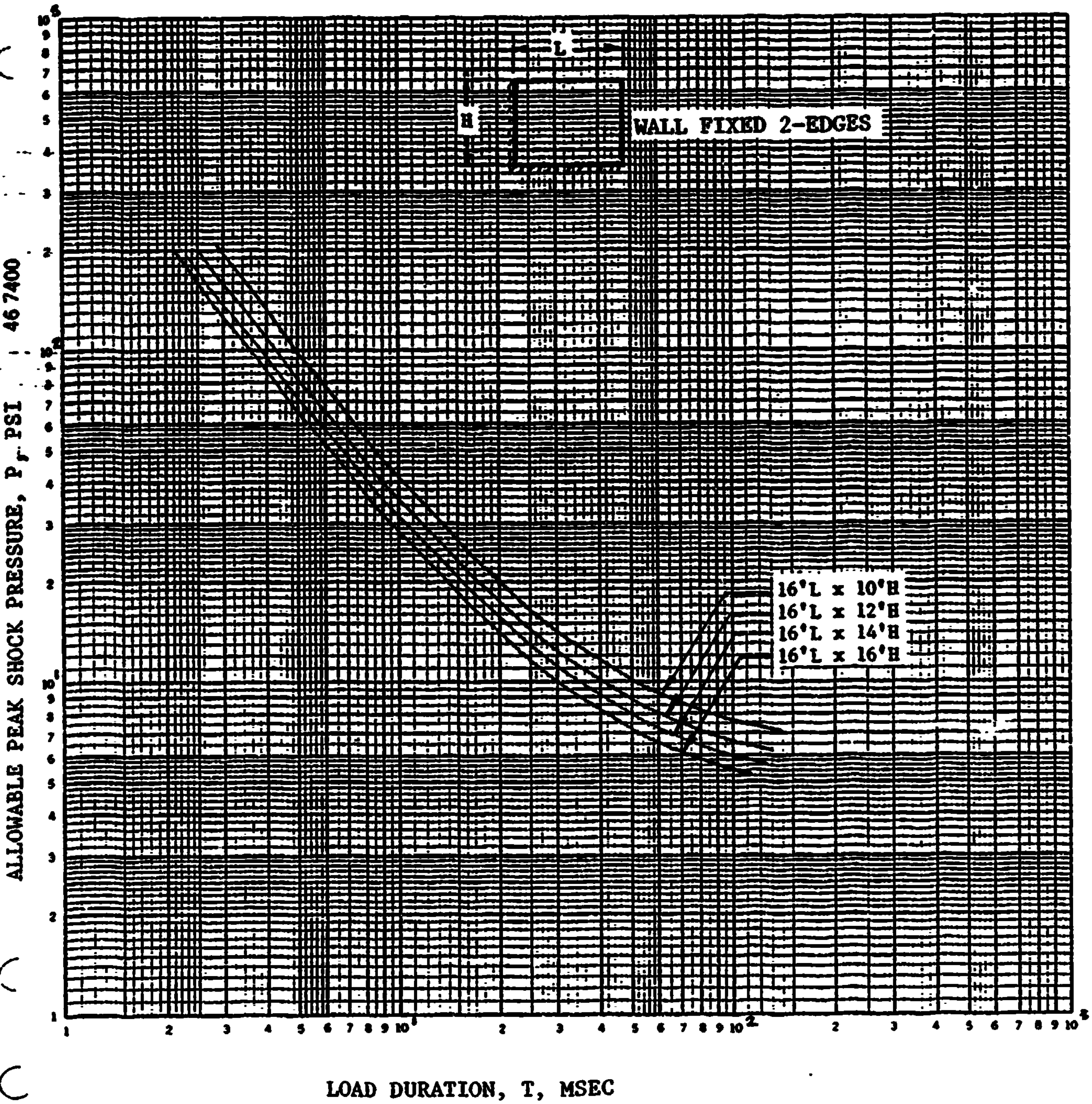


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FIGURE 3-8 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION

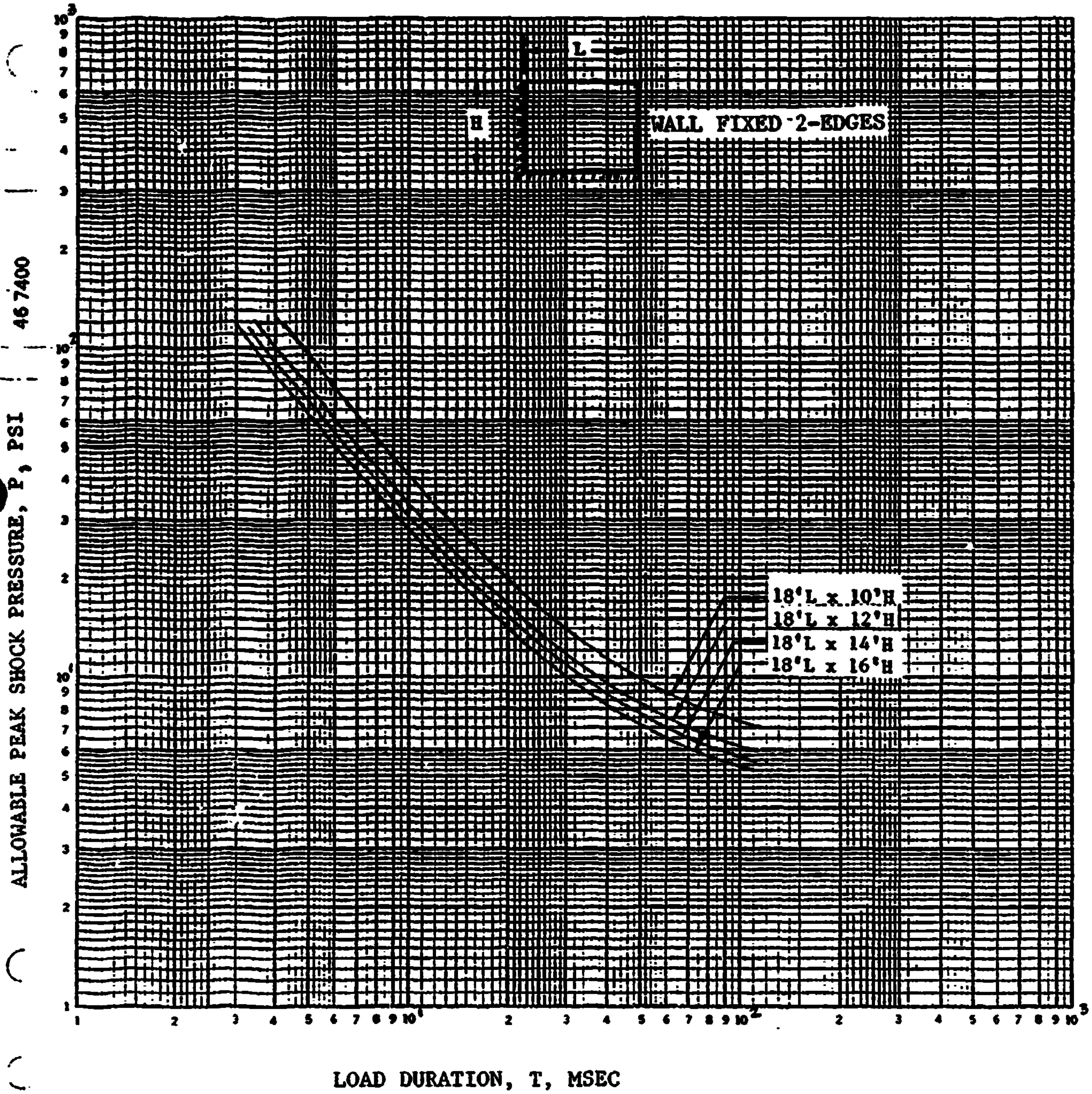


FIGURE 3-9 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION

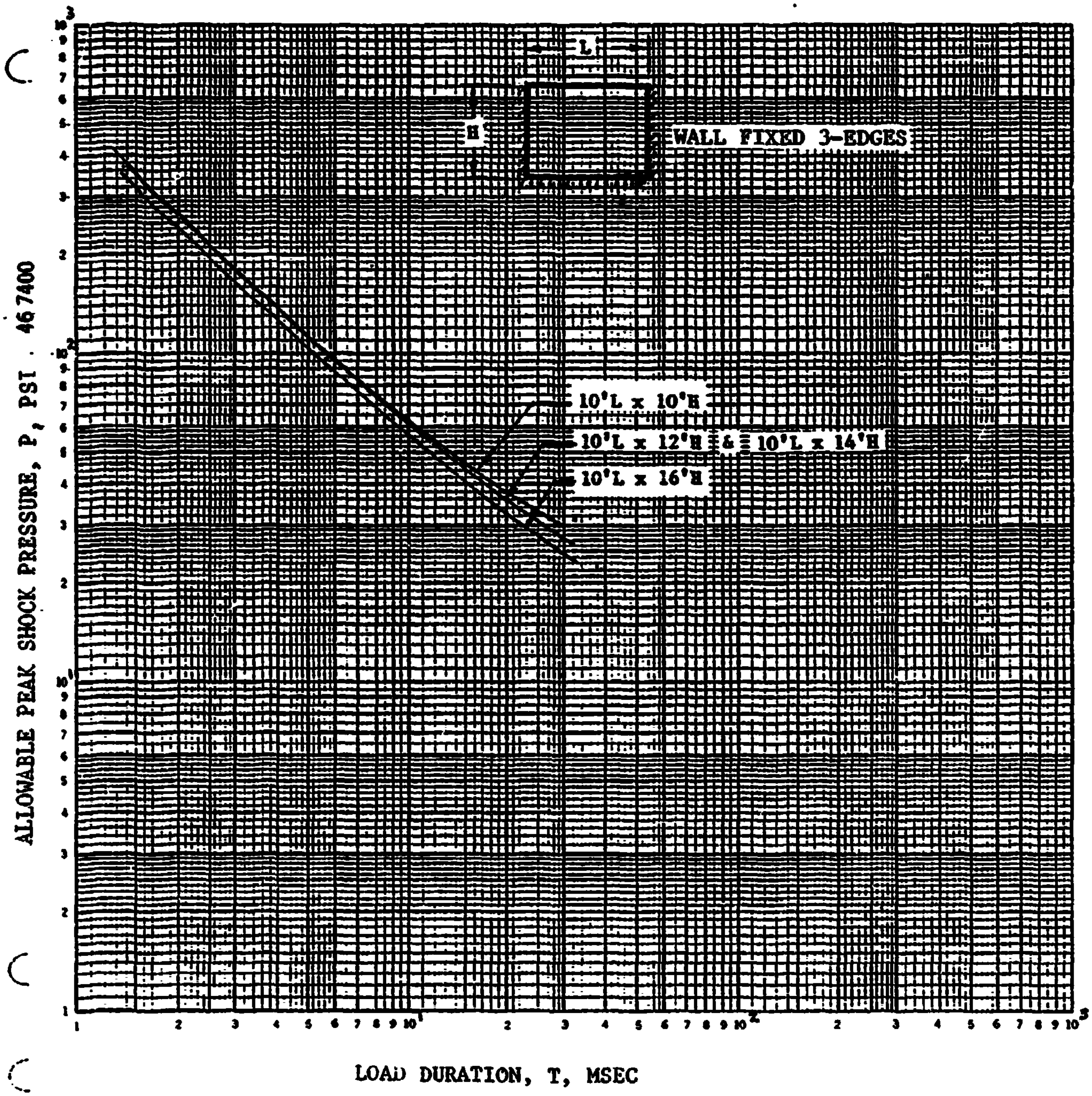


FIGURE 3-10 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION

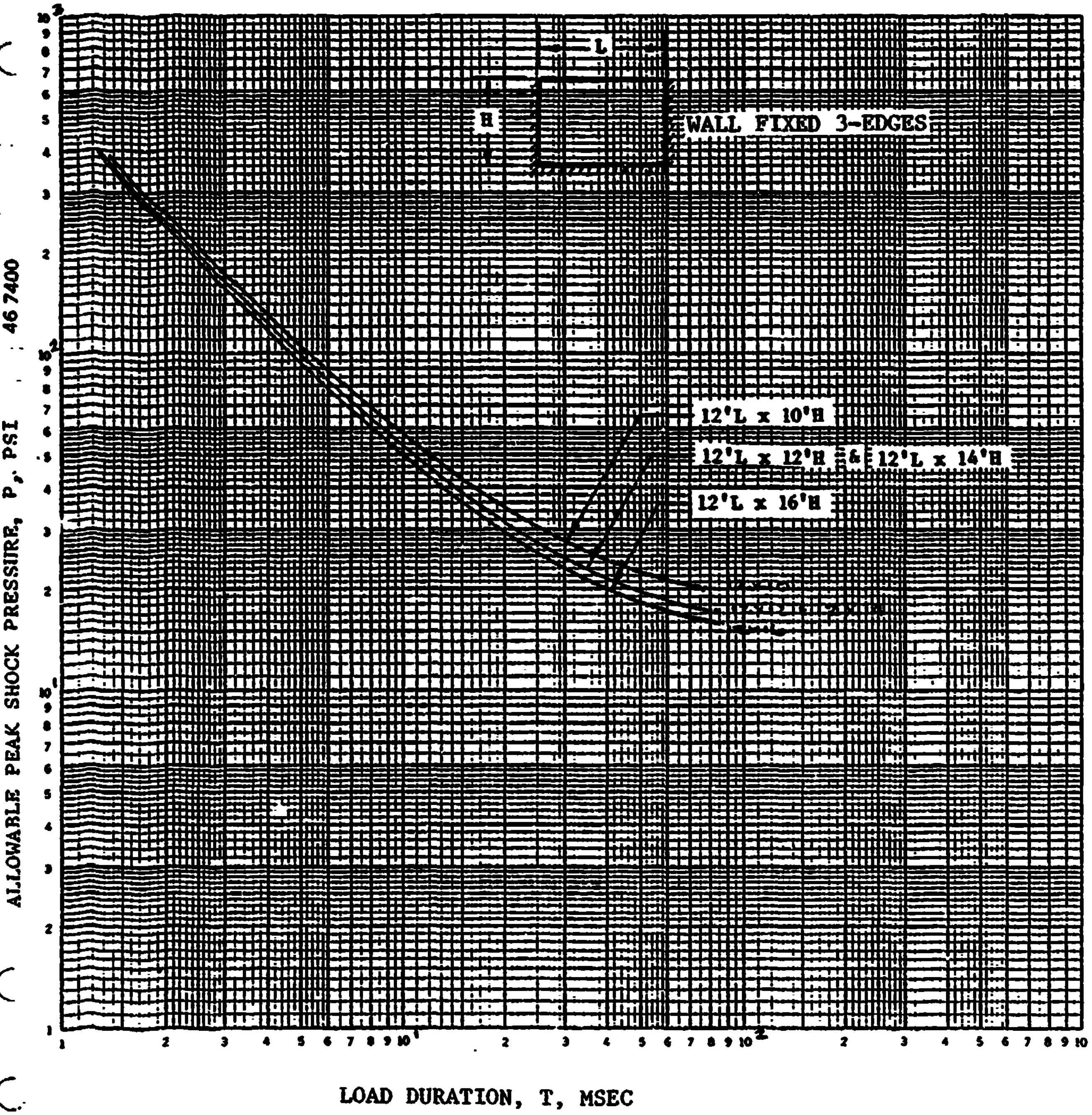


FIGURE 3-11 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION

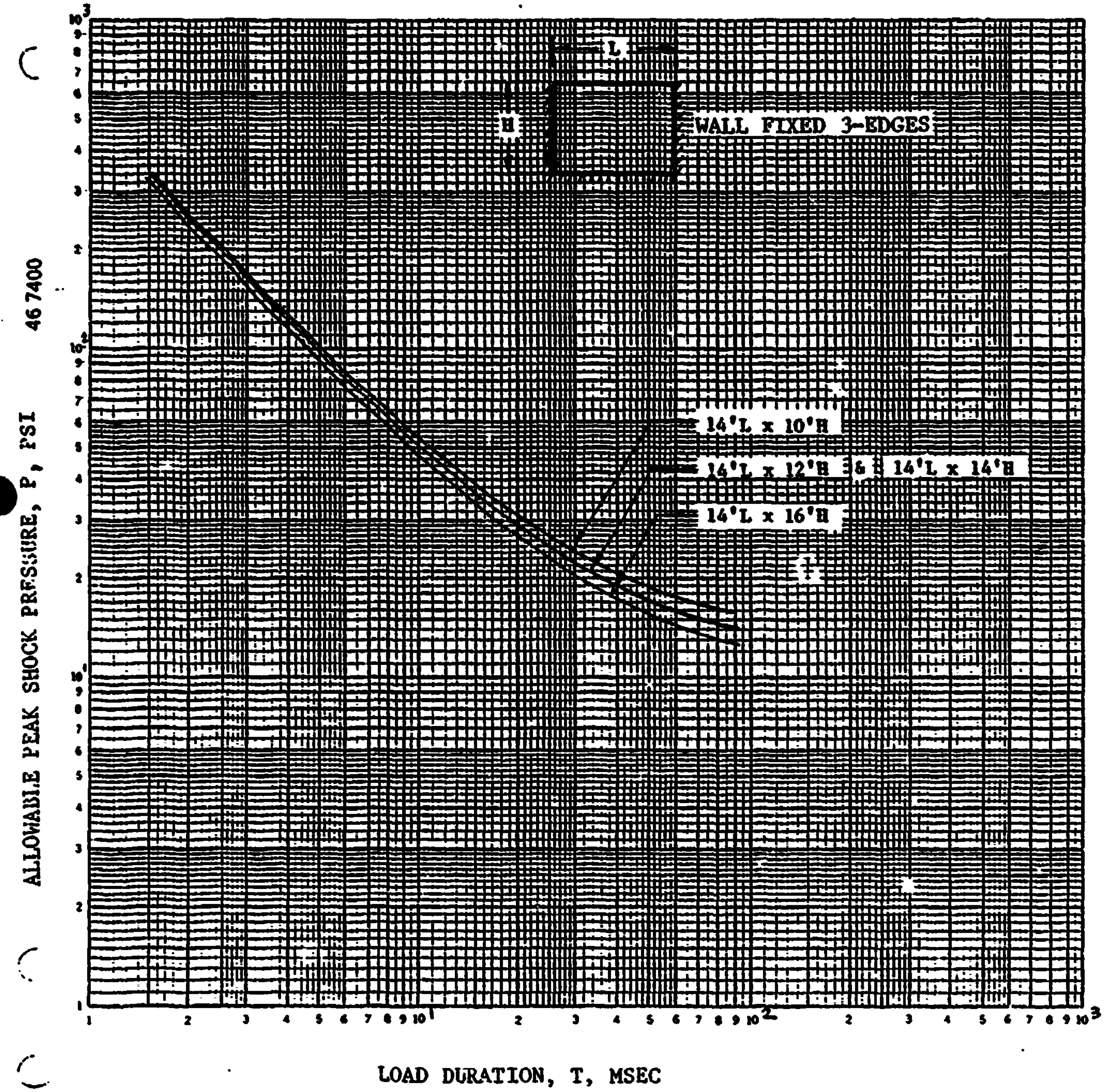
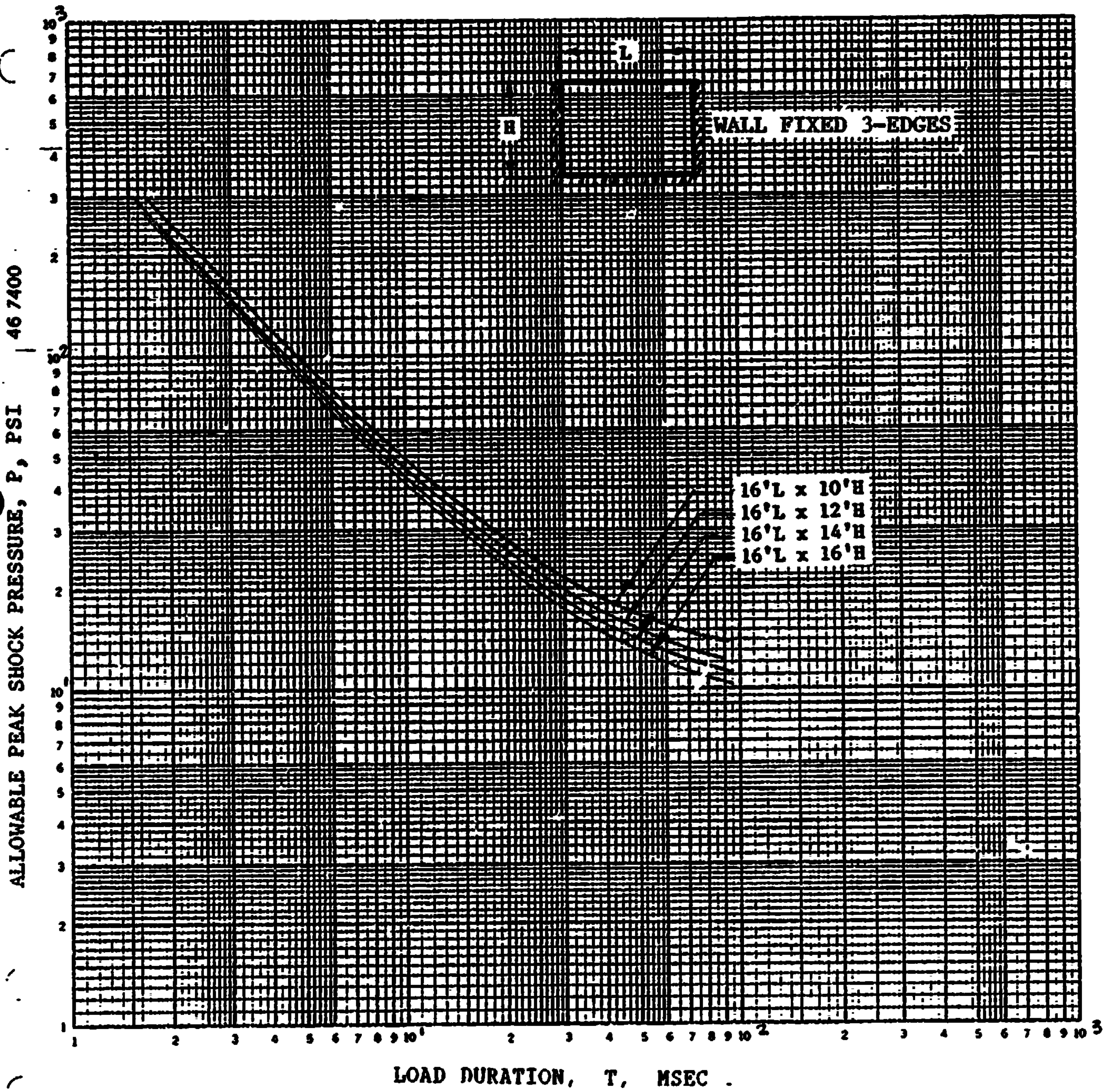


FIGURE 3-12 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION



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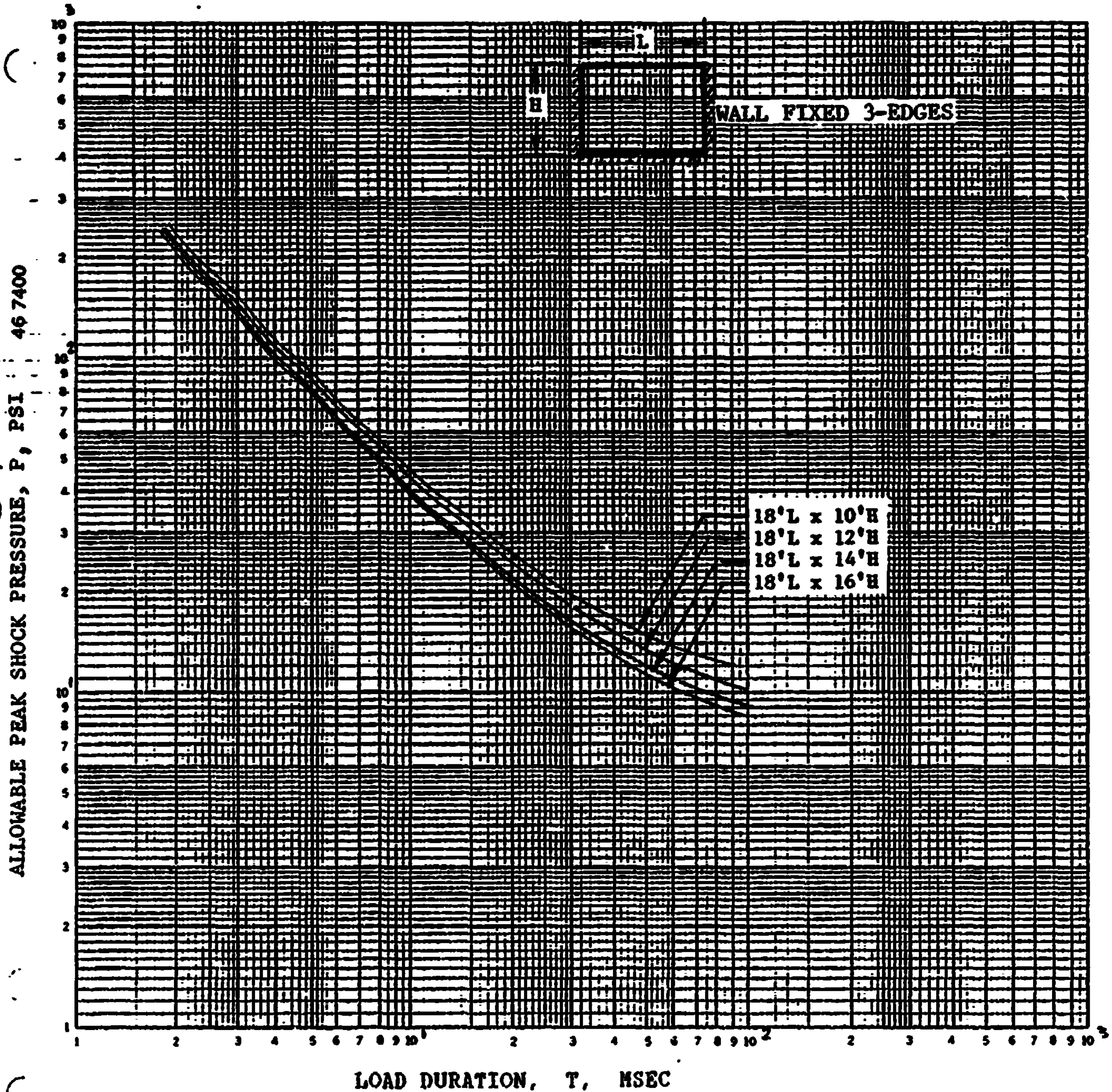


FIGURE 3-14 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION

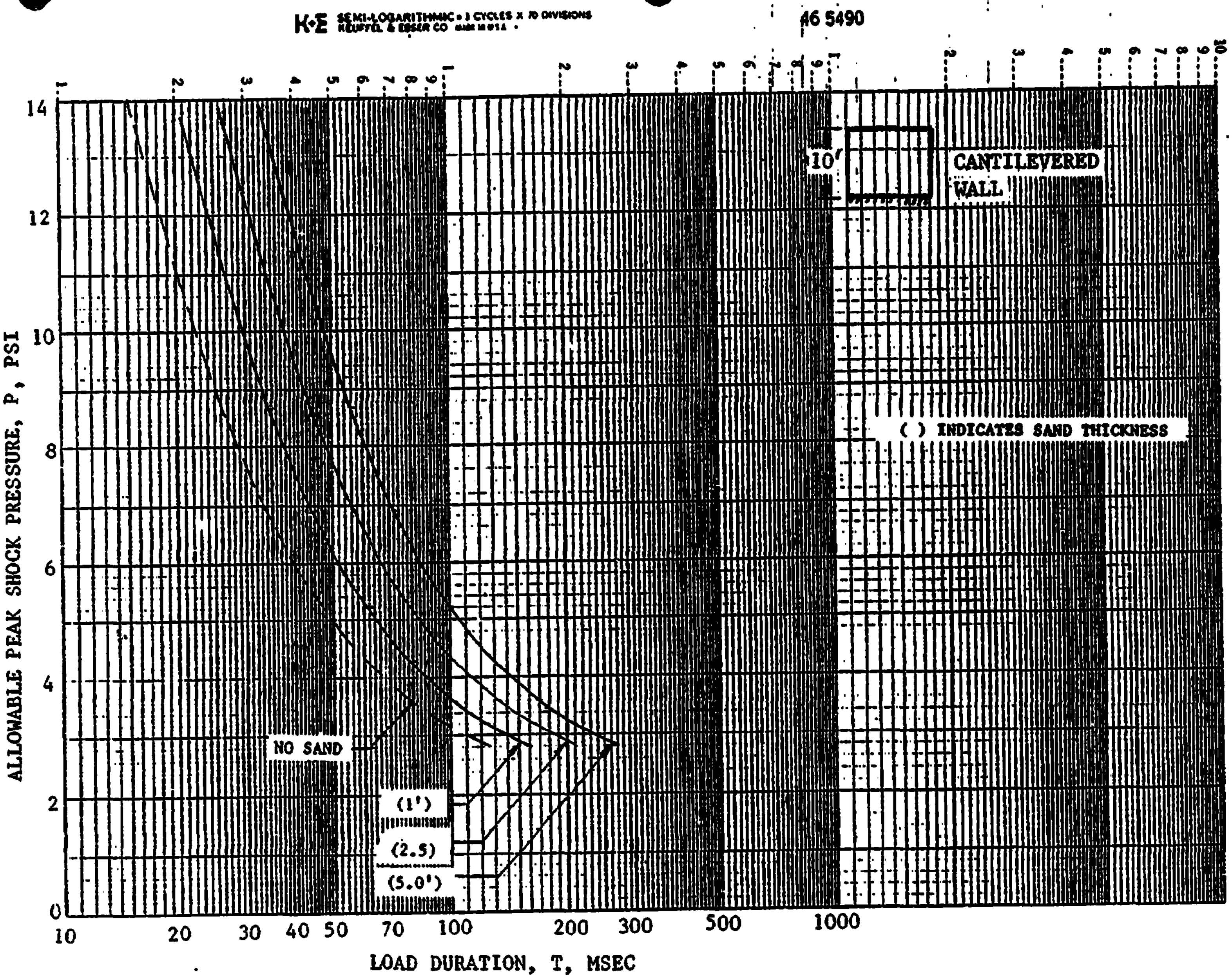
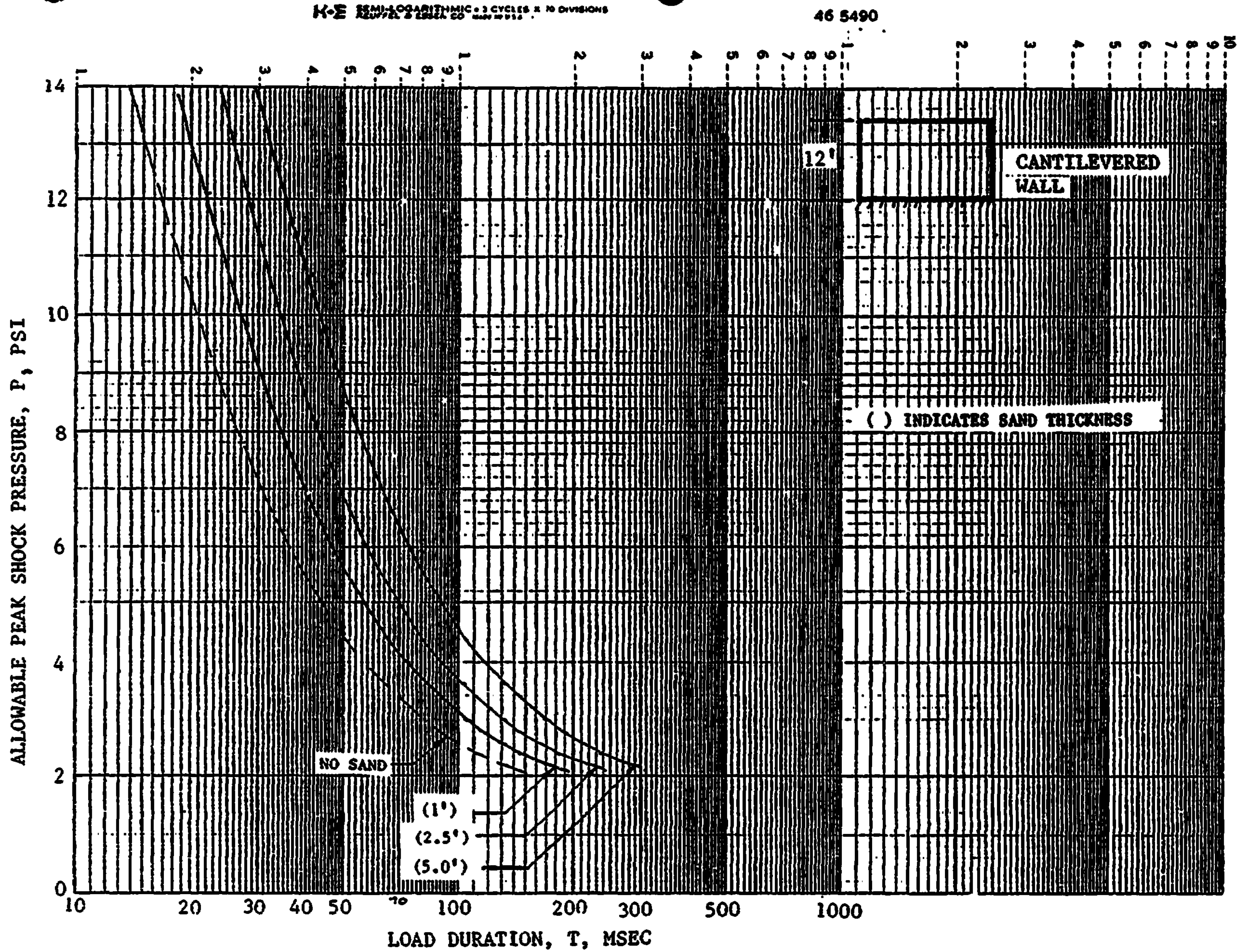


FIGURE 3-15 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION



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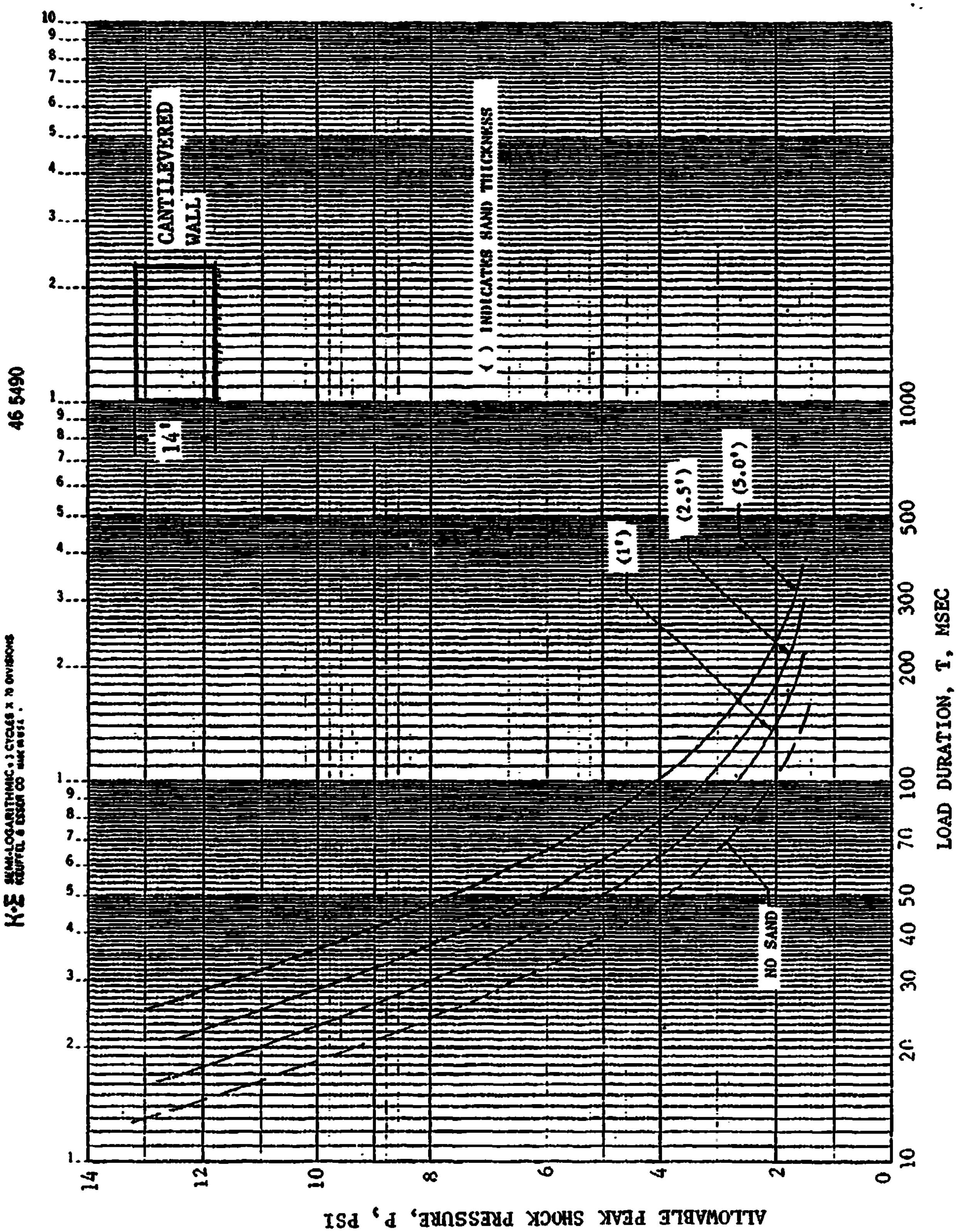


FIGURE 3-17 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION

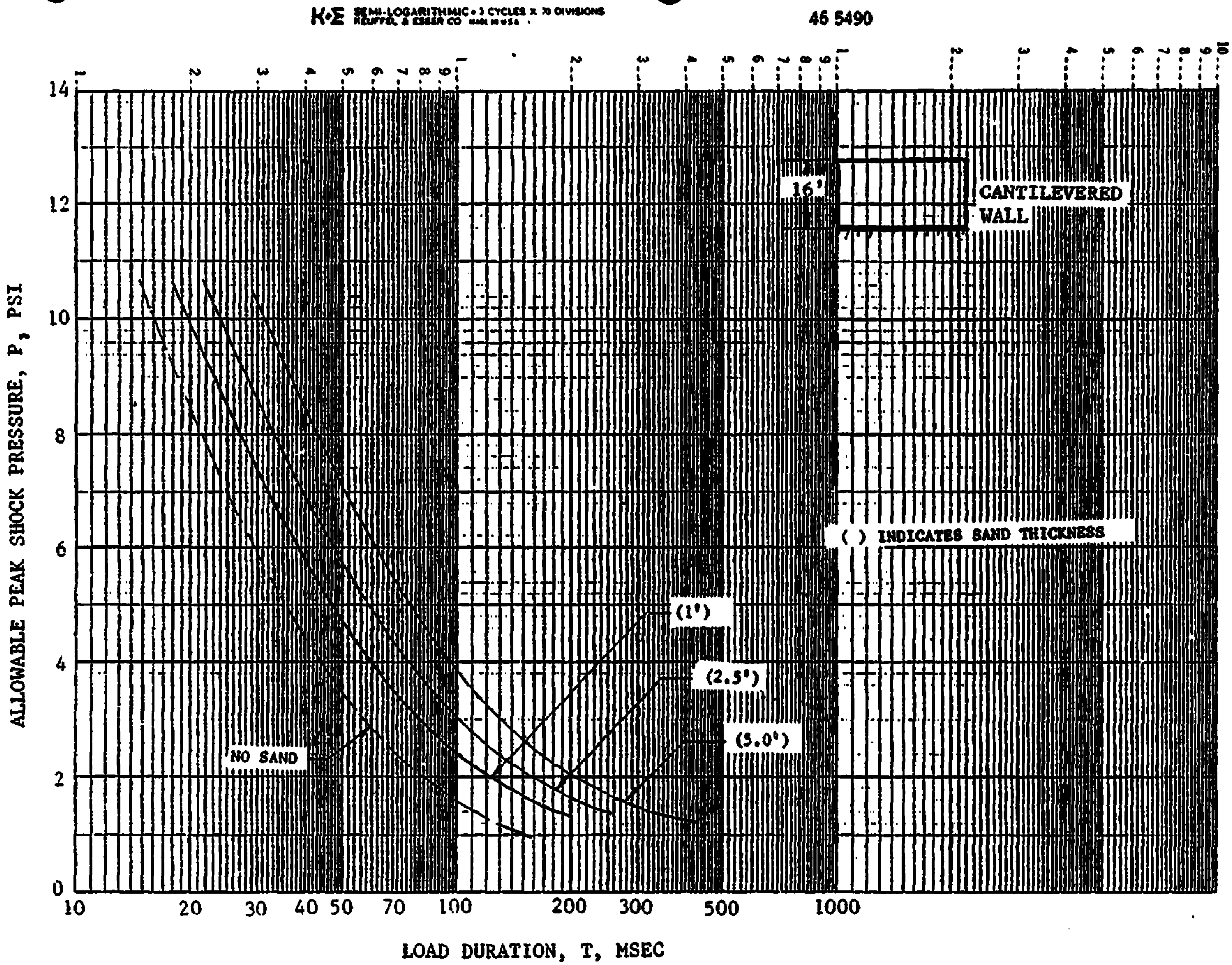
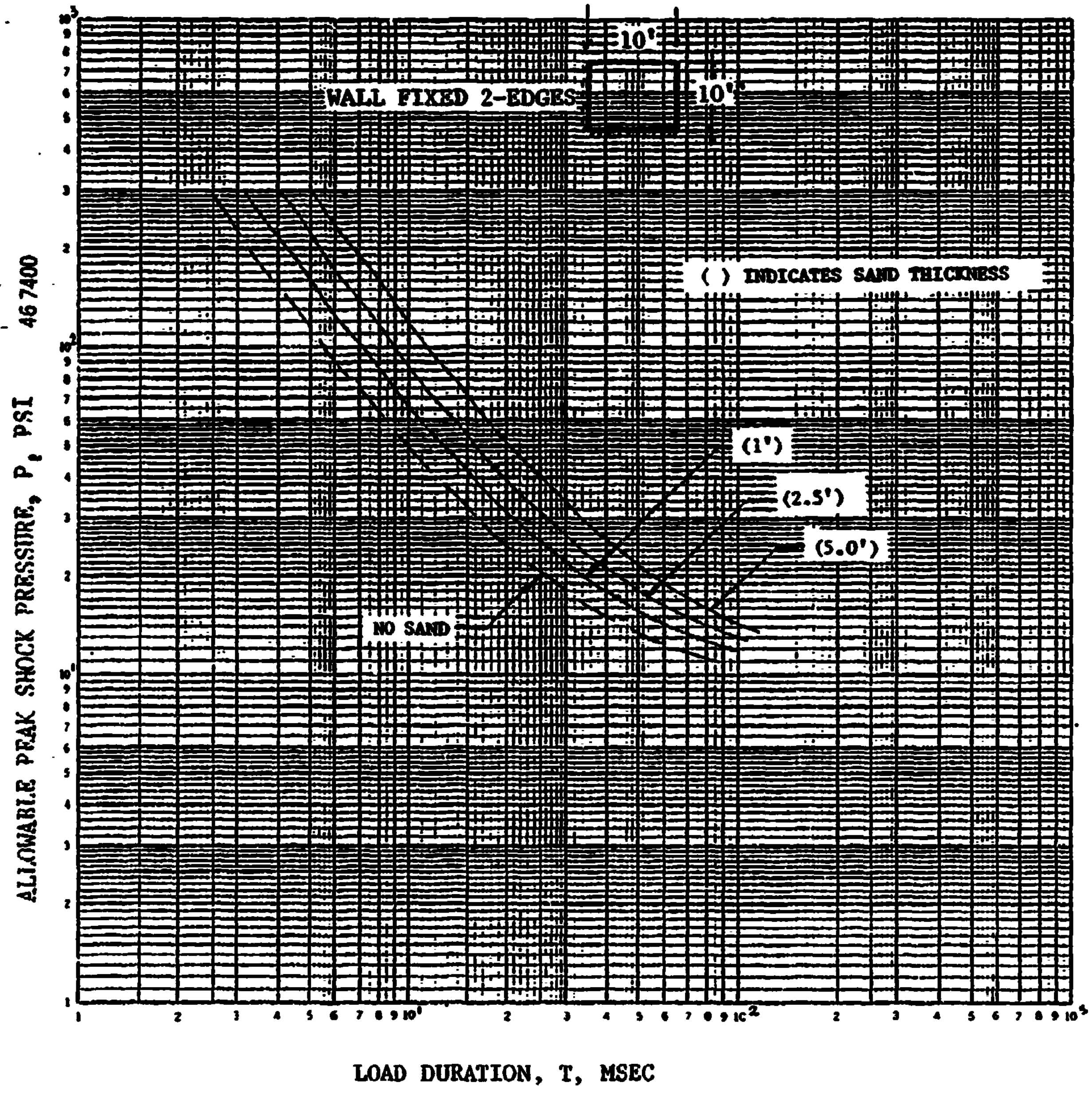


FIGURE 3-18 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION



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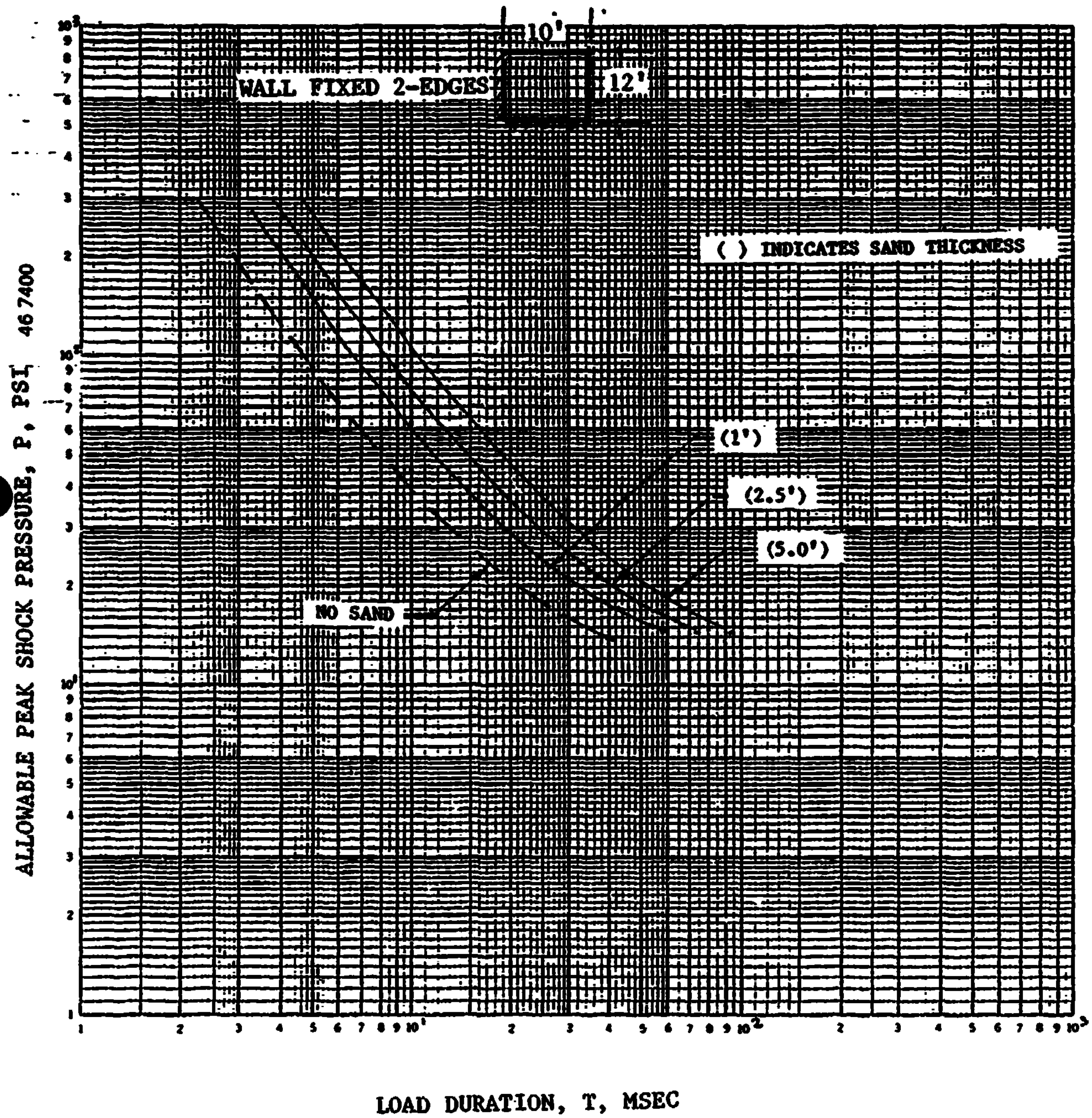

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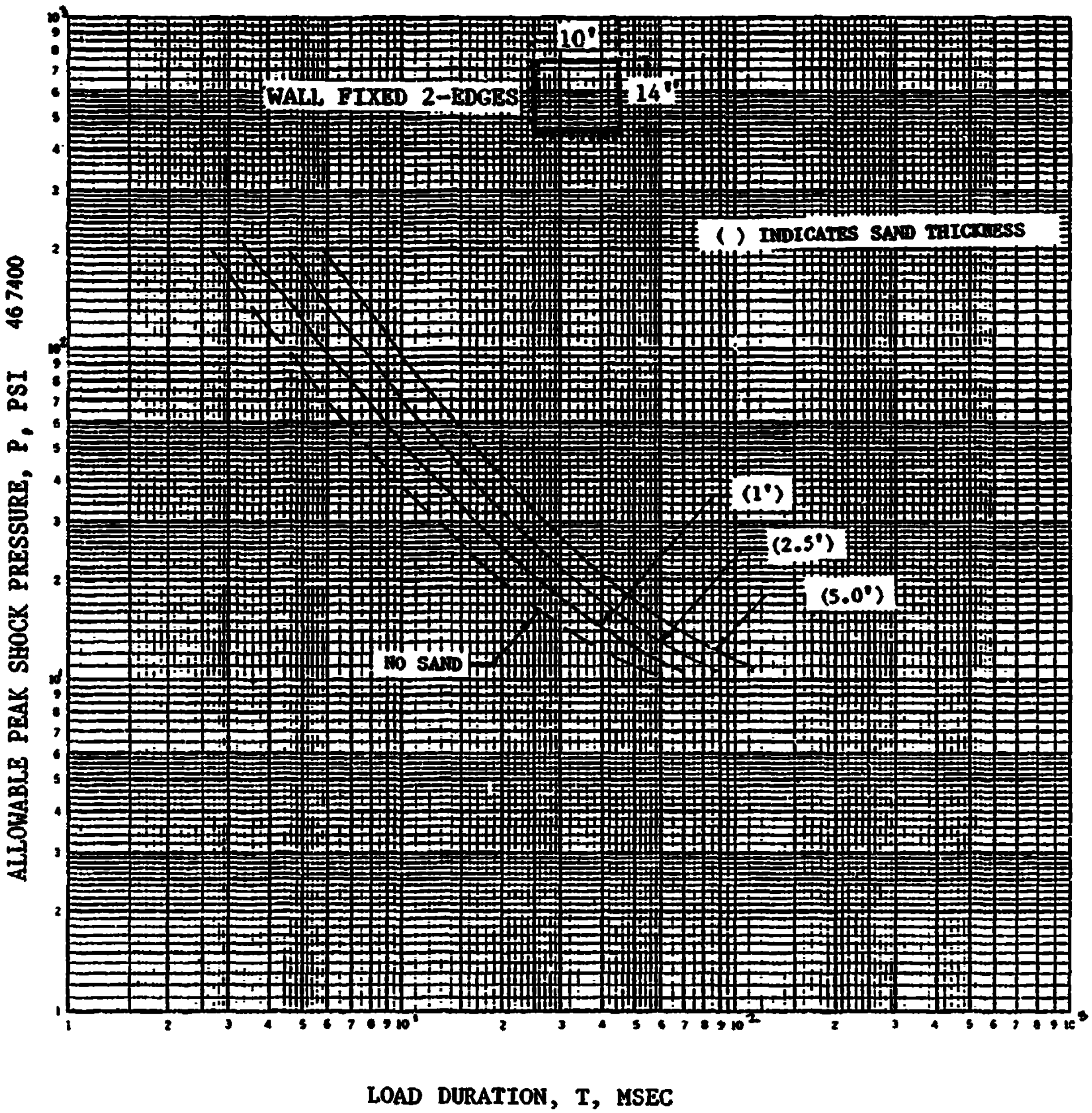

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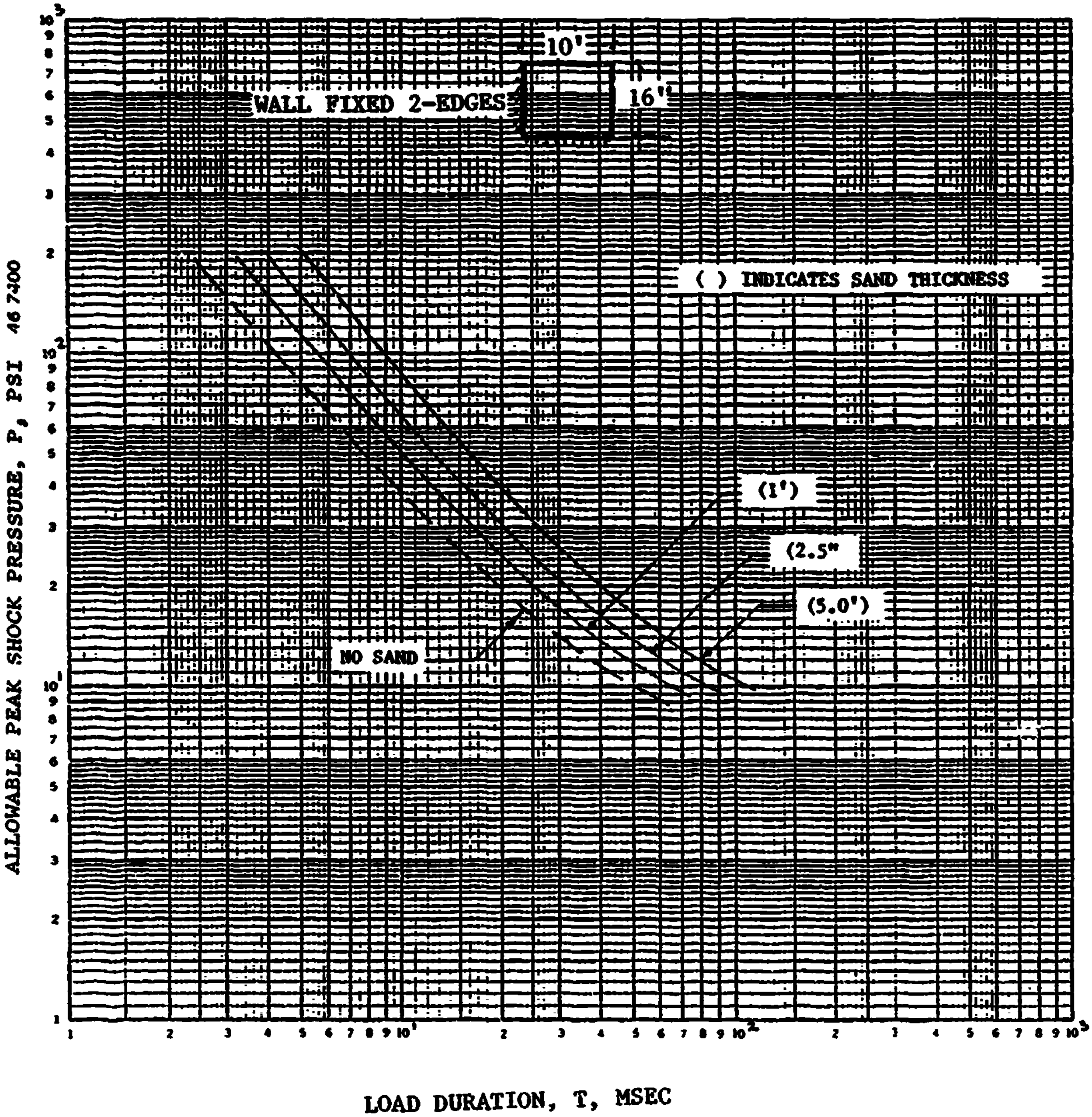

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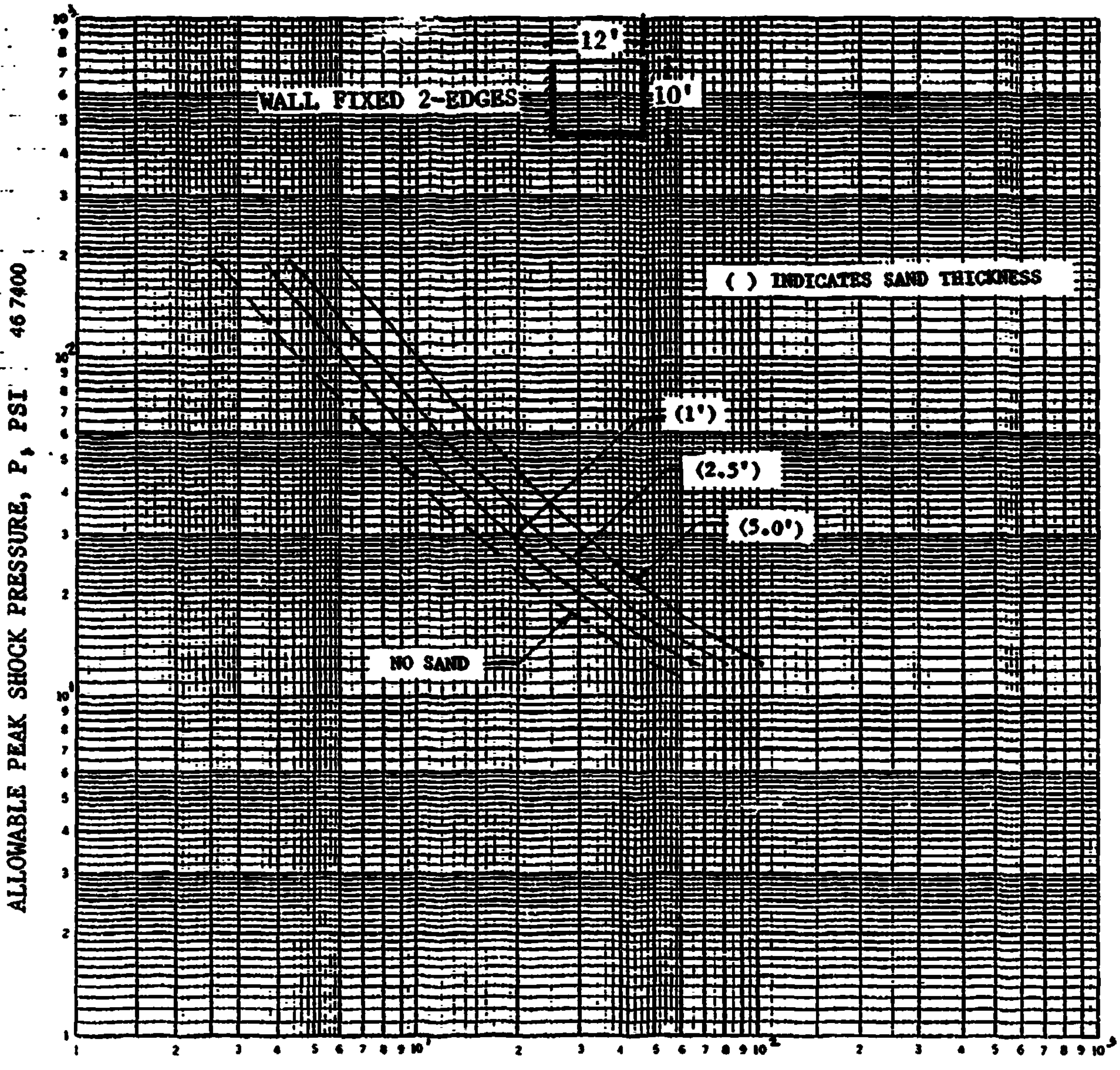

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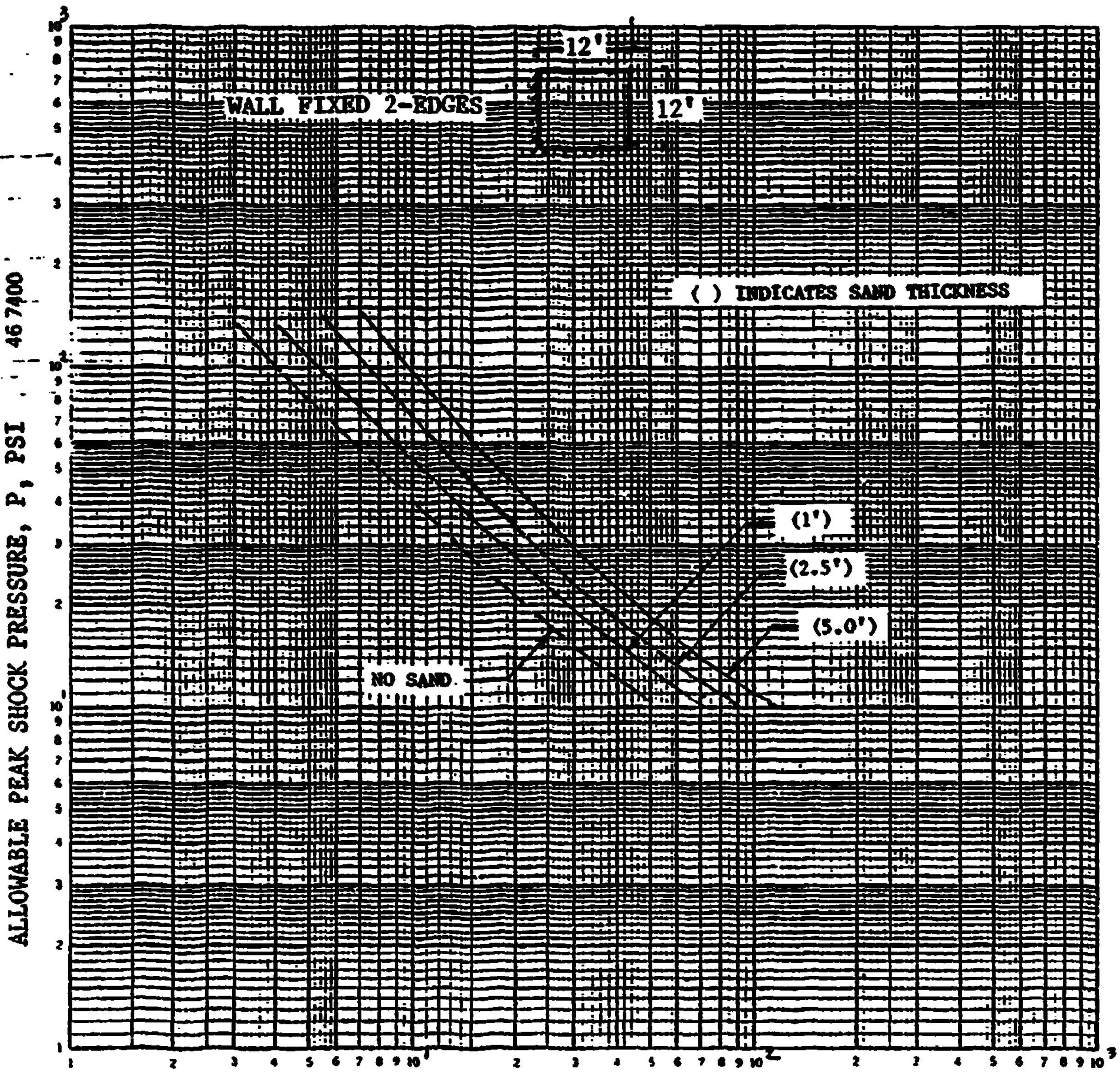

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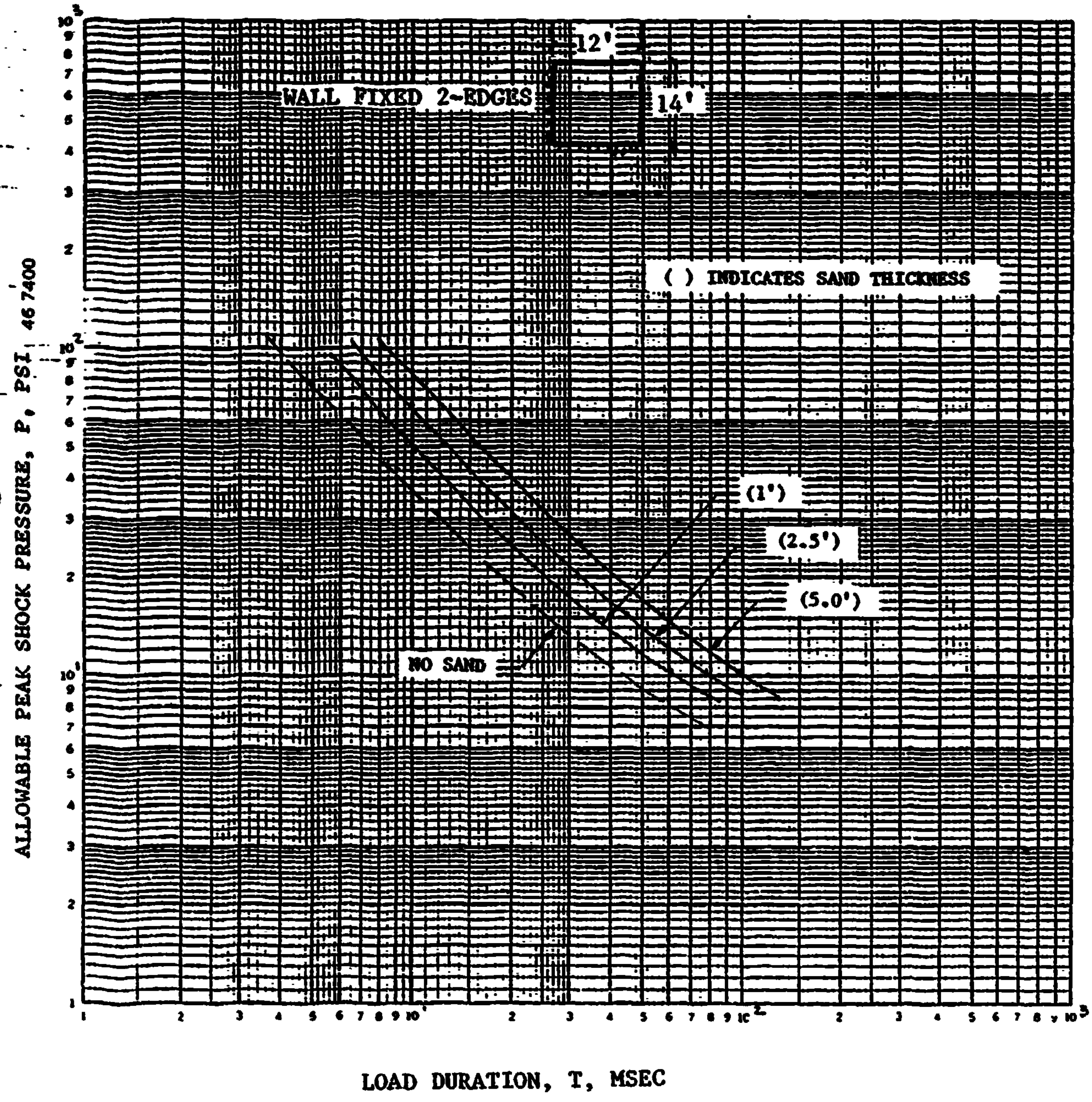

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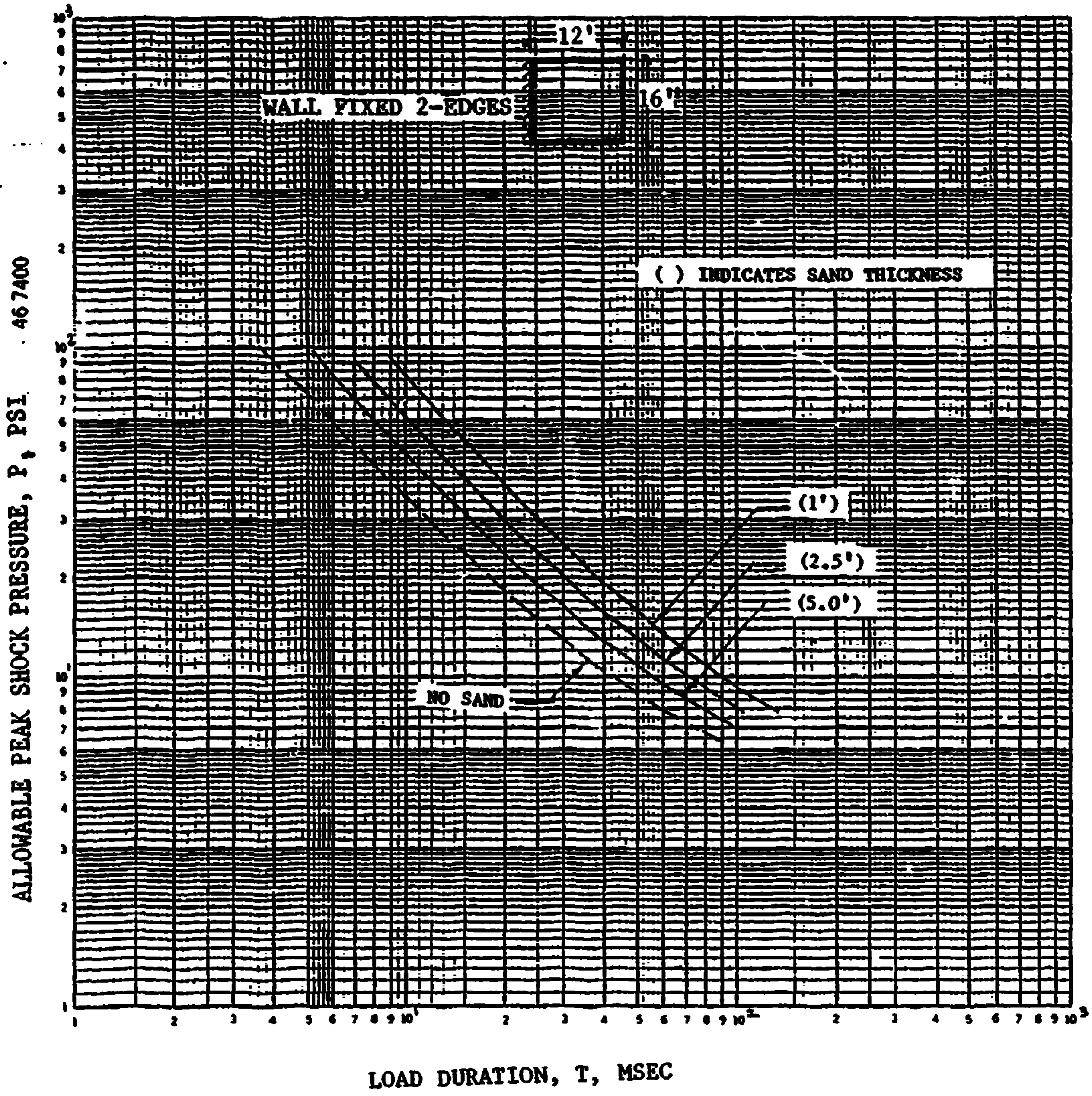

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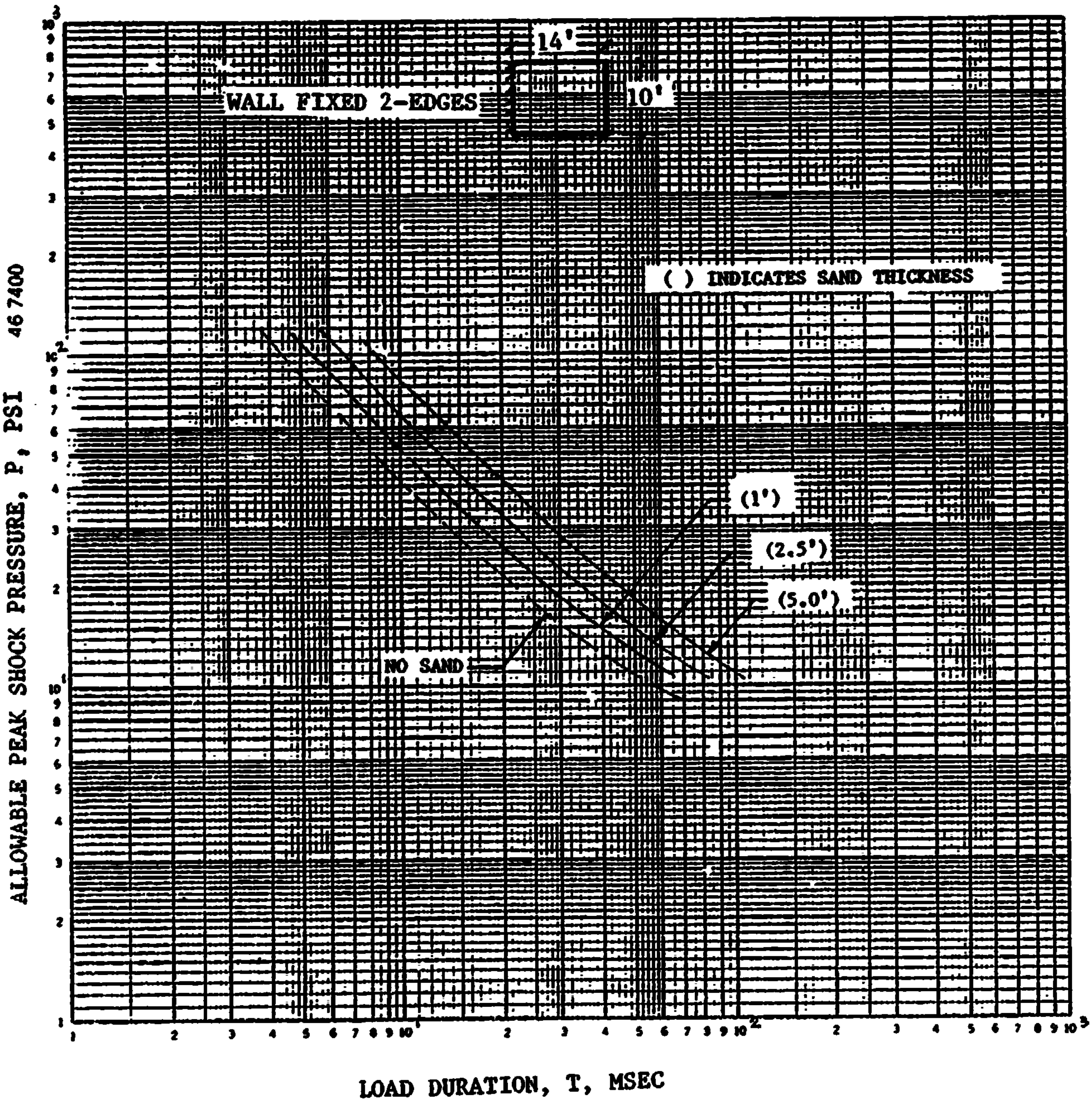

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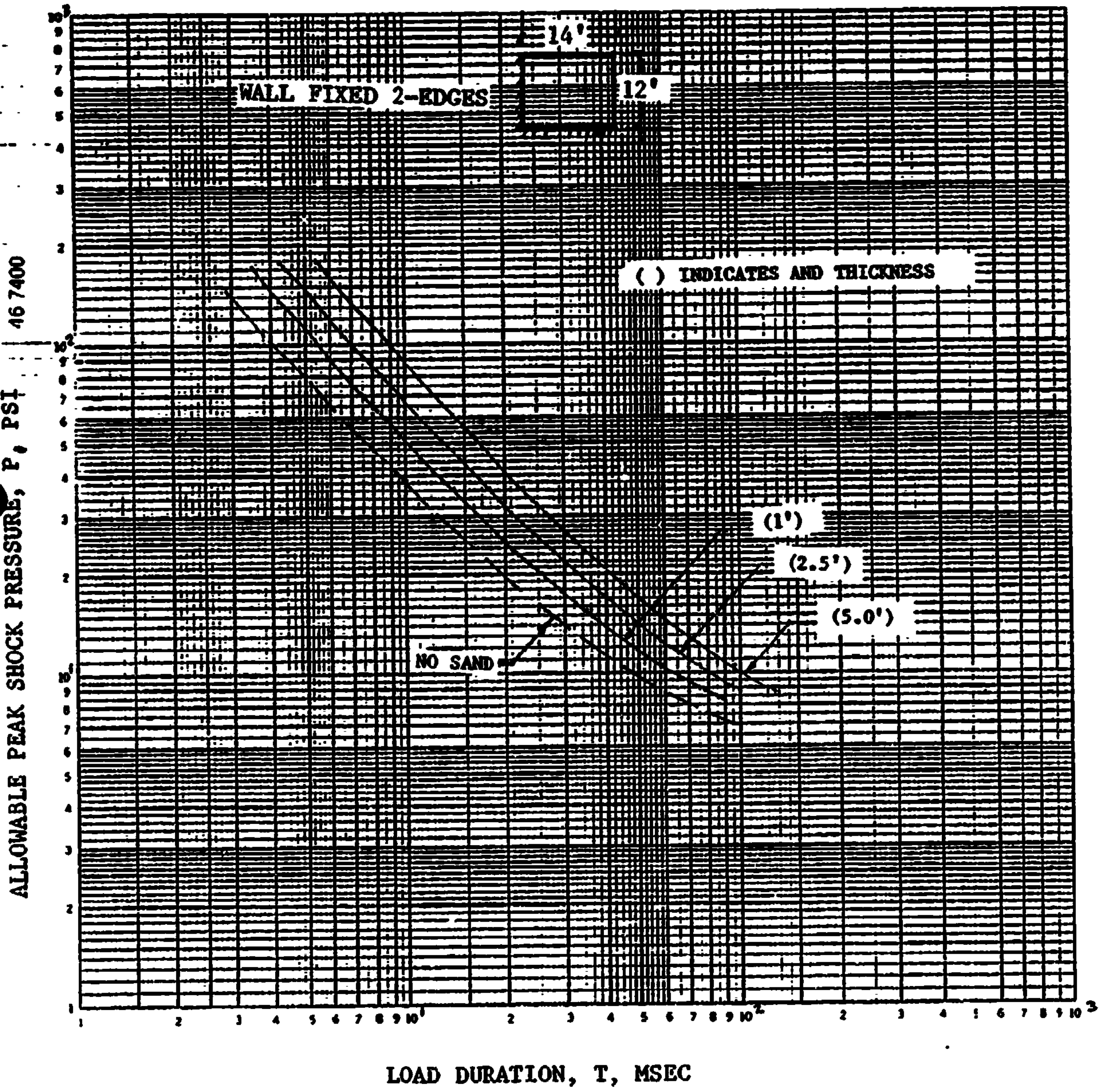

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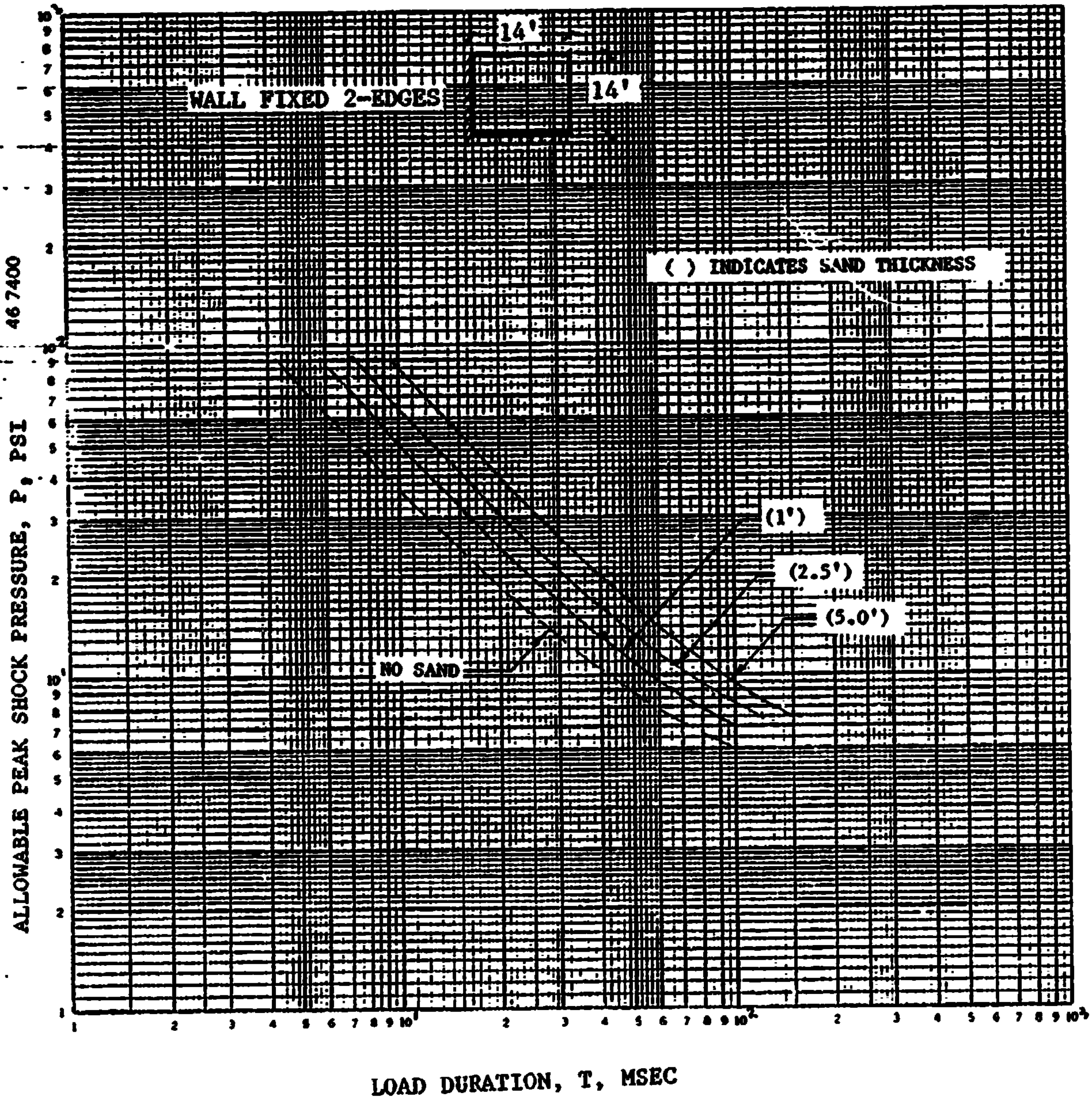

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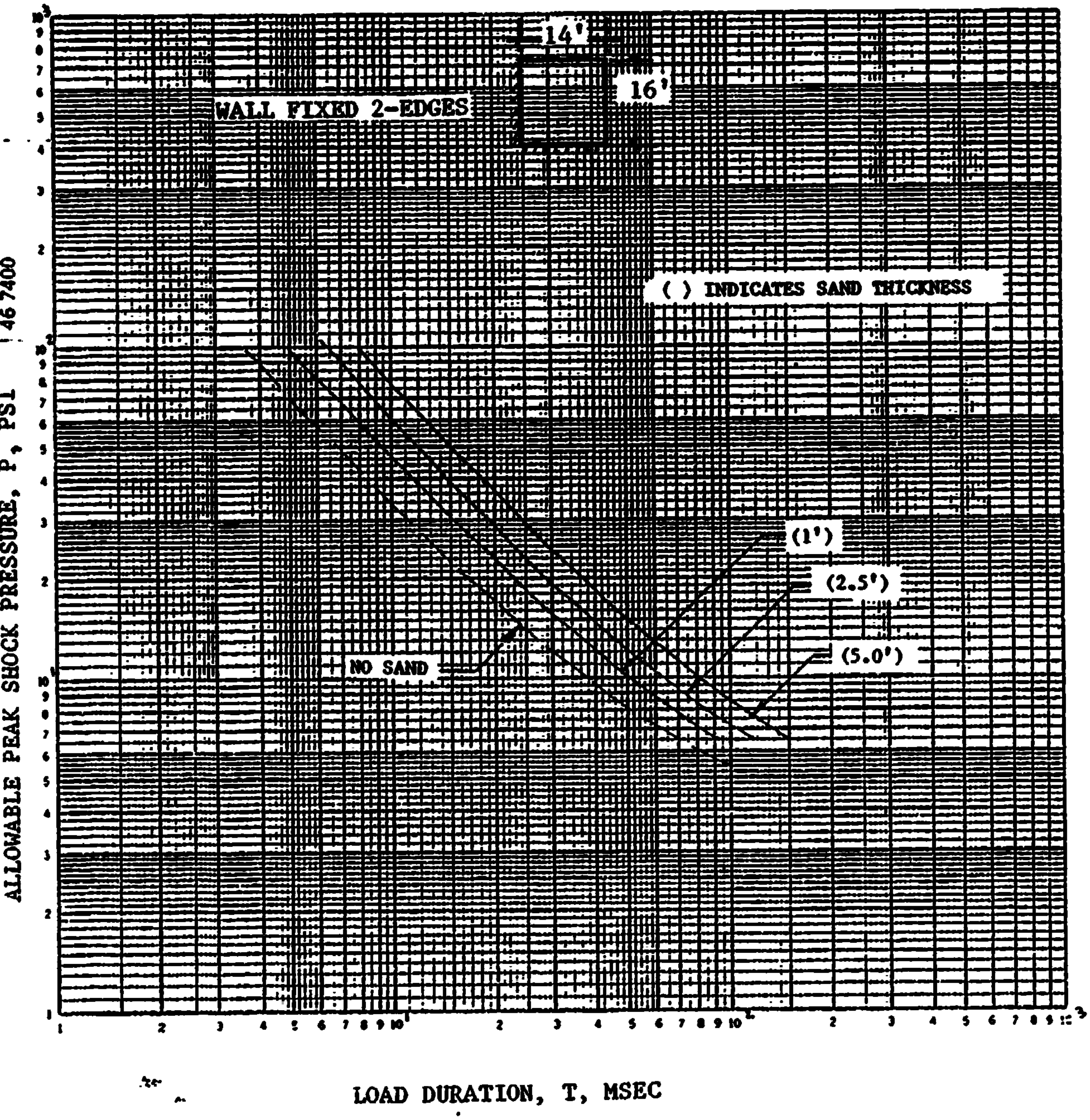

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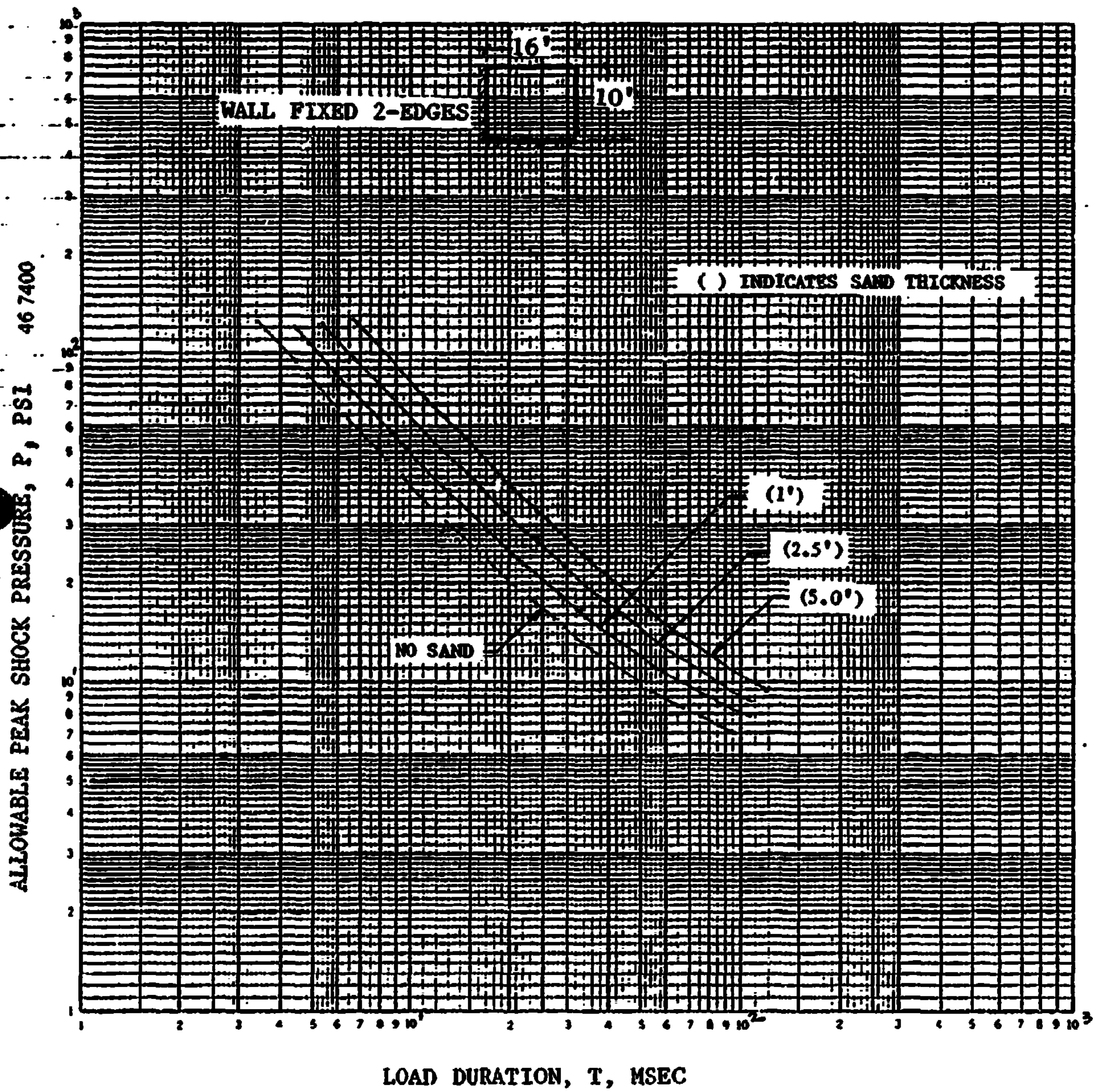

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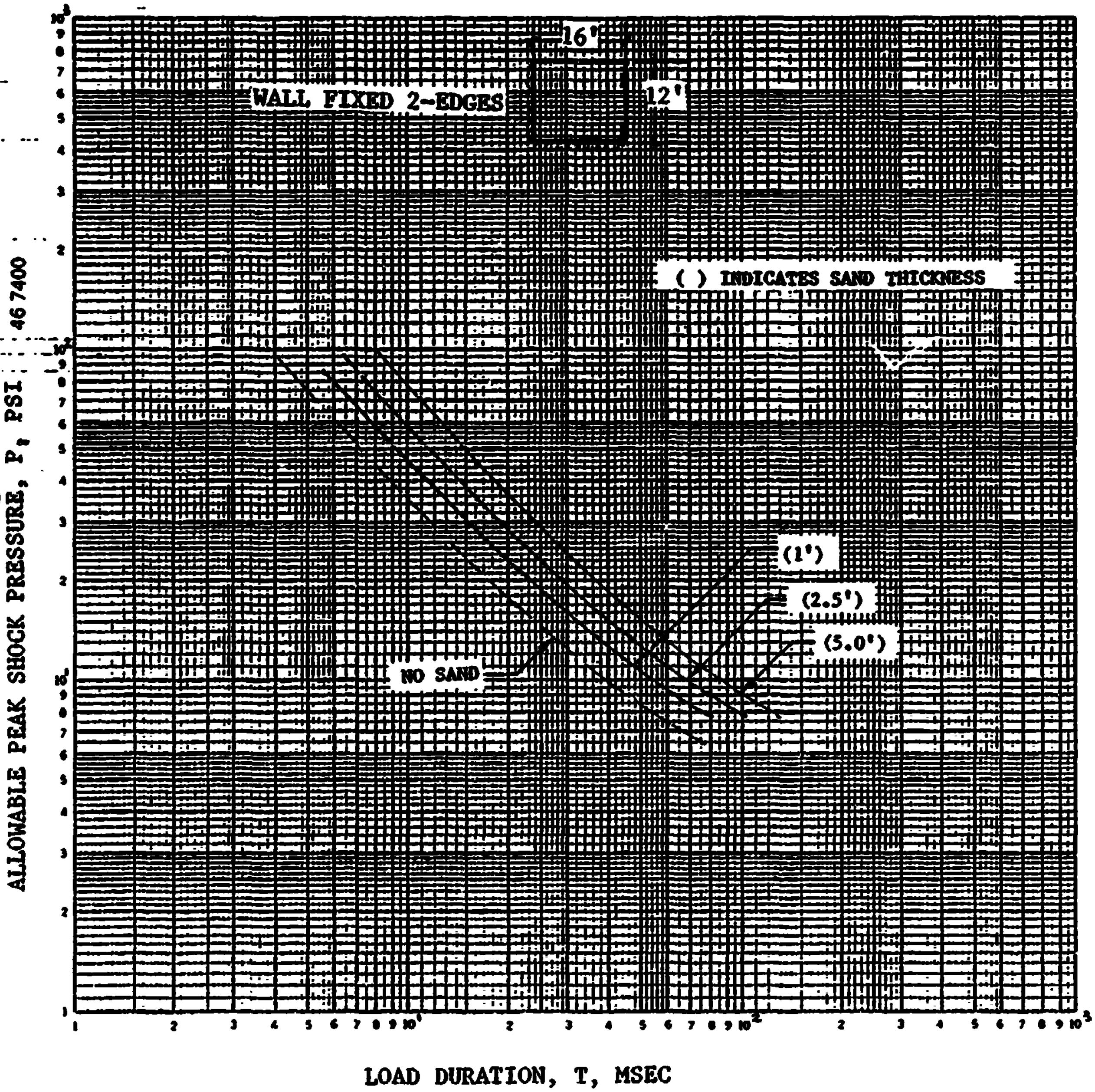

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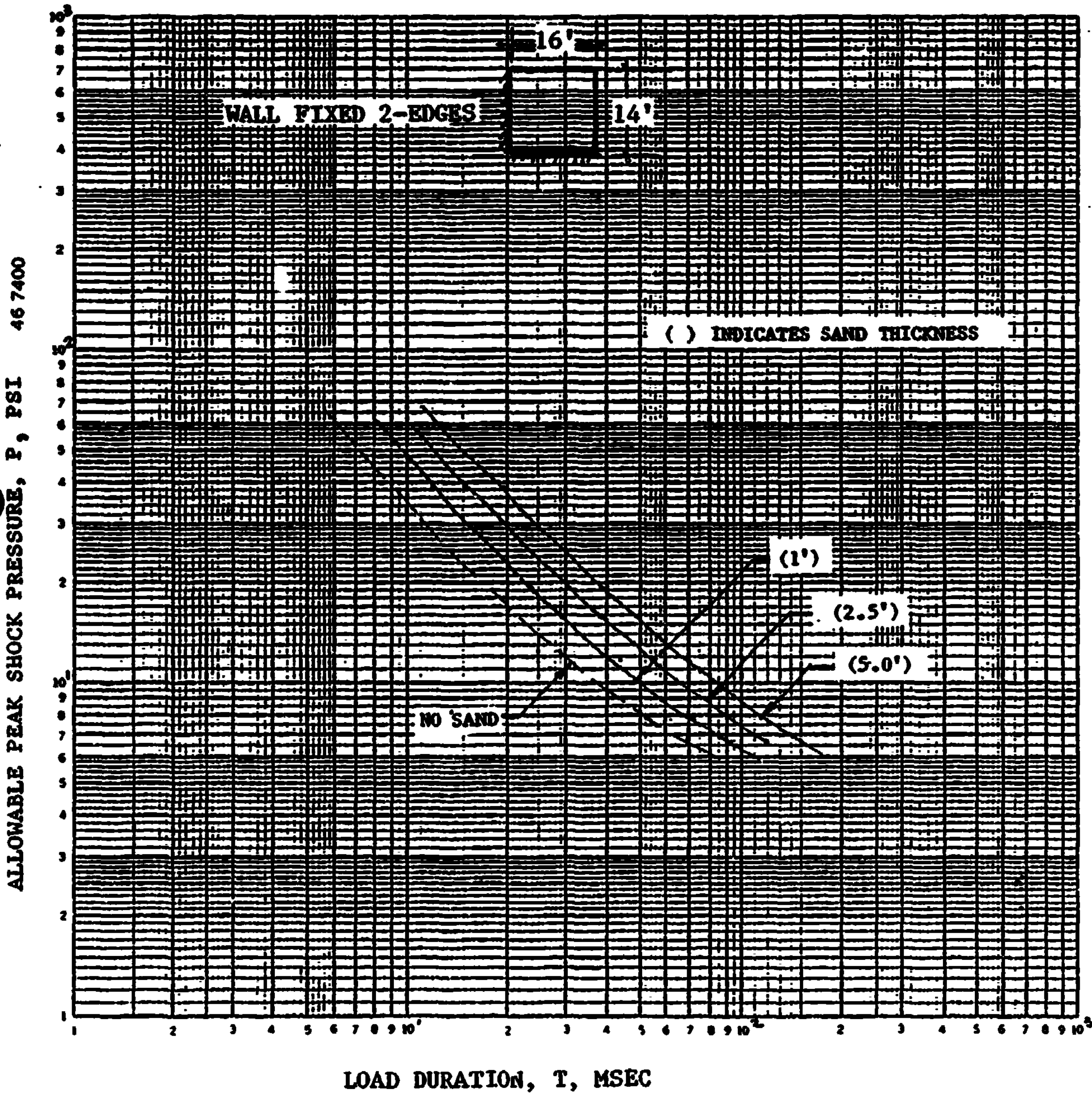

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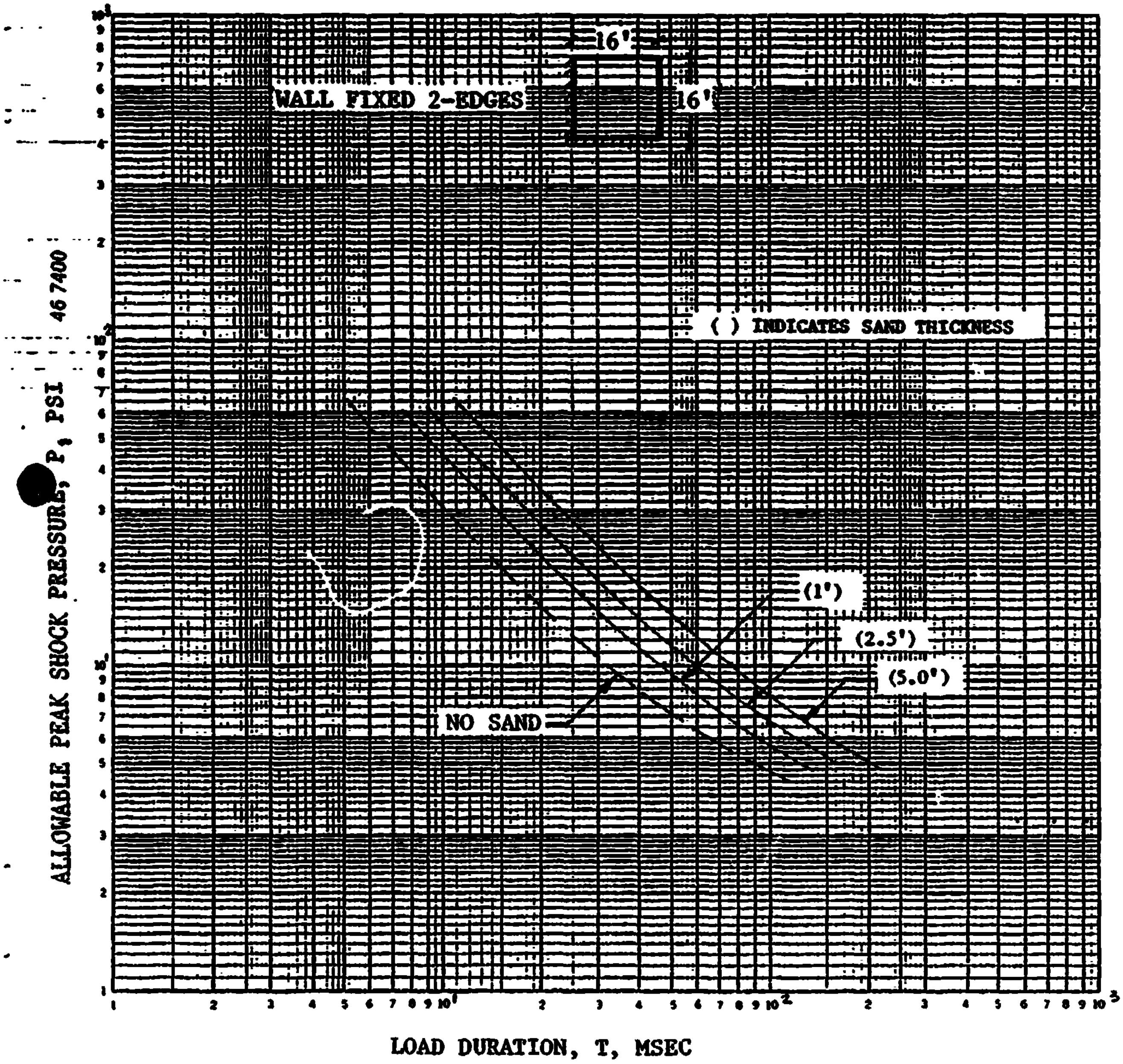
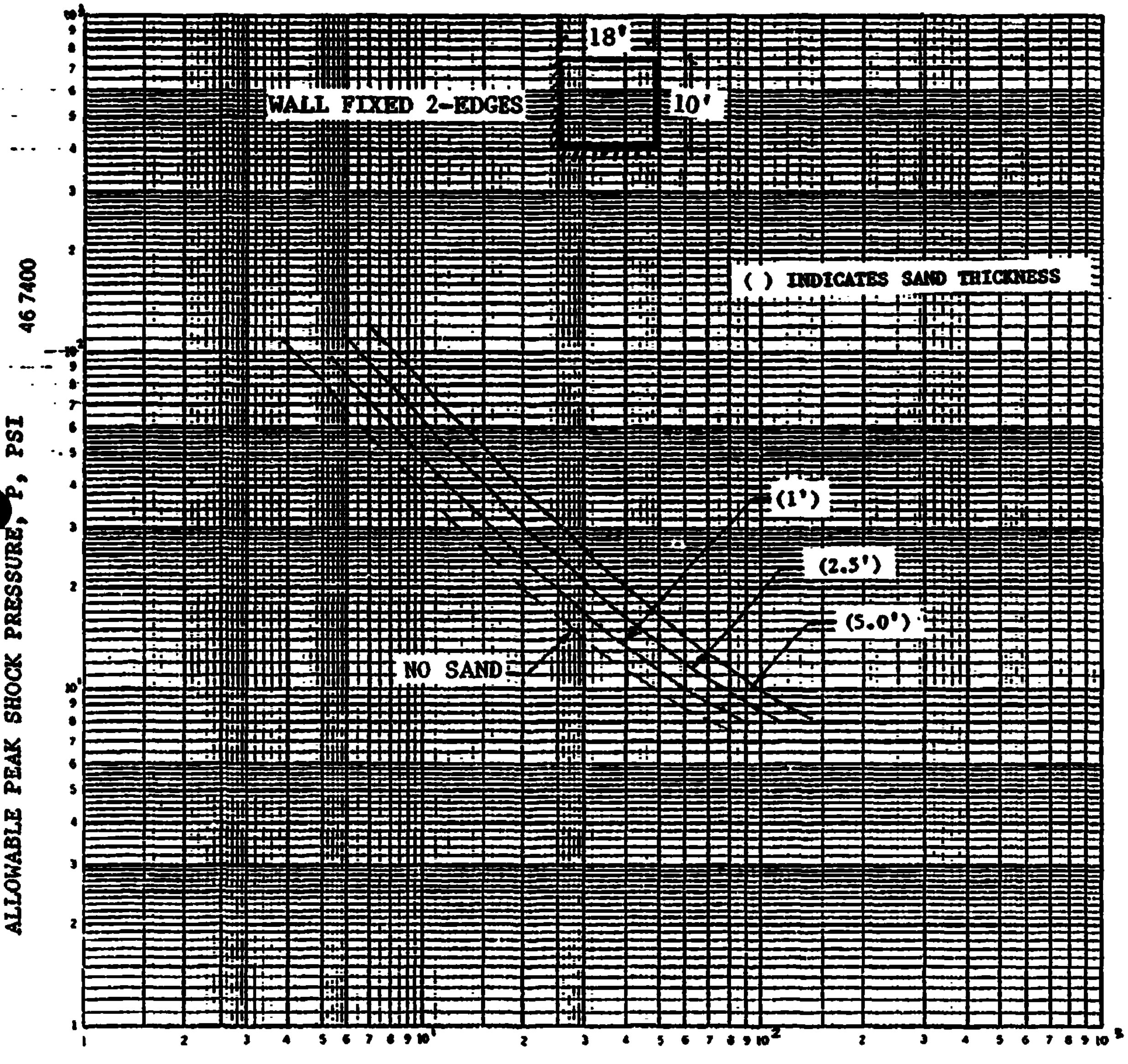


FIGURE 3-34 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION



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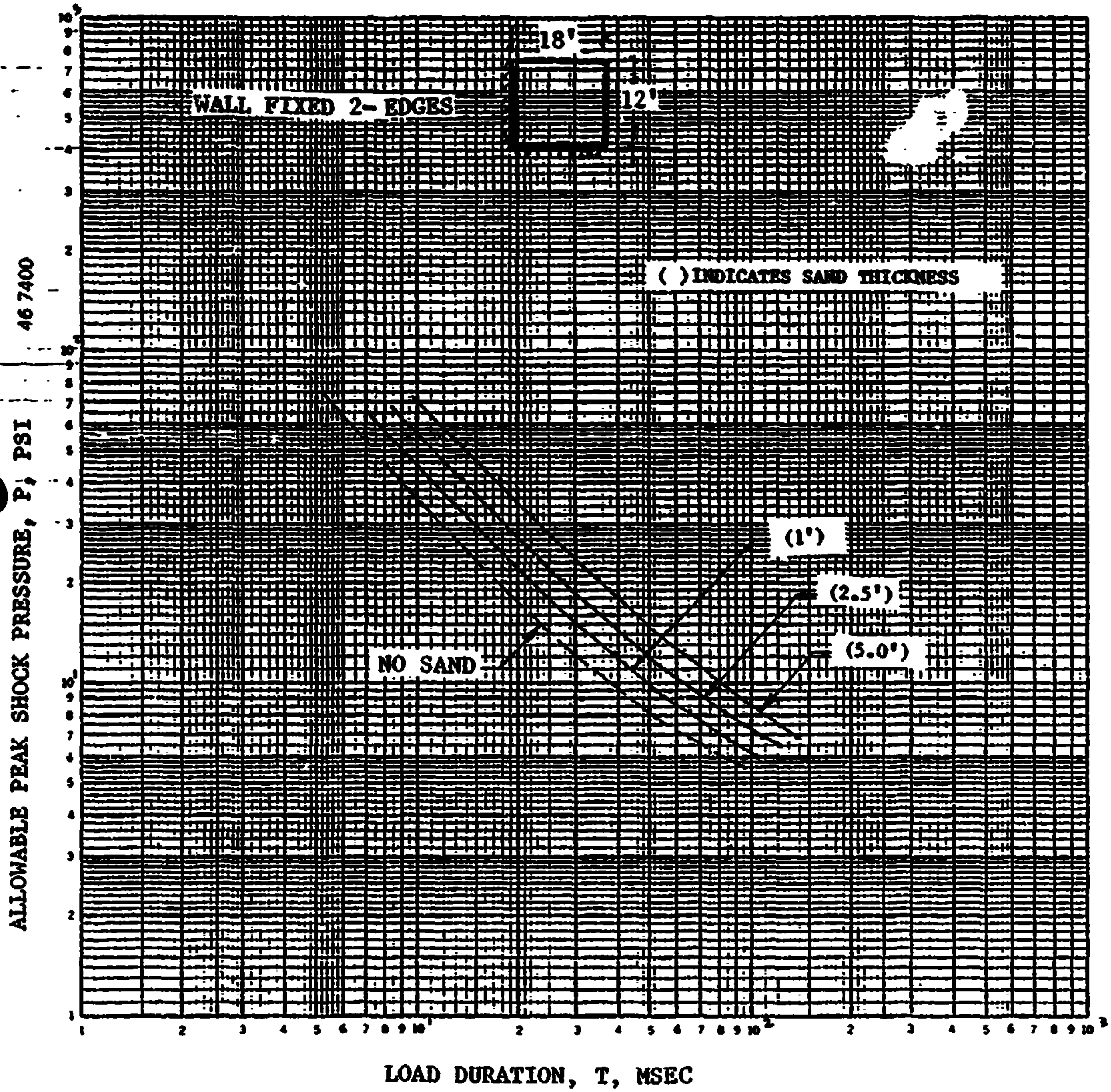


FIGURE 3-36 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION

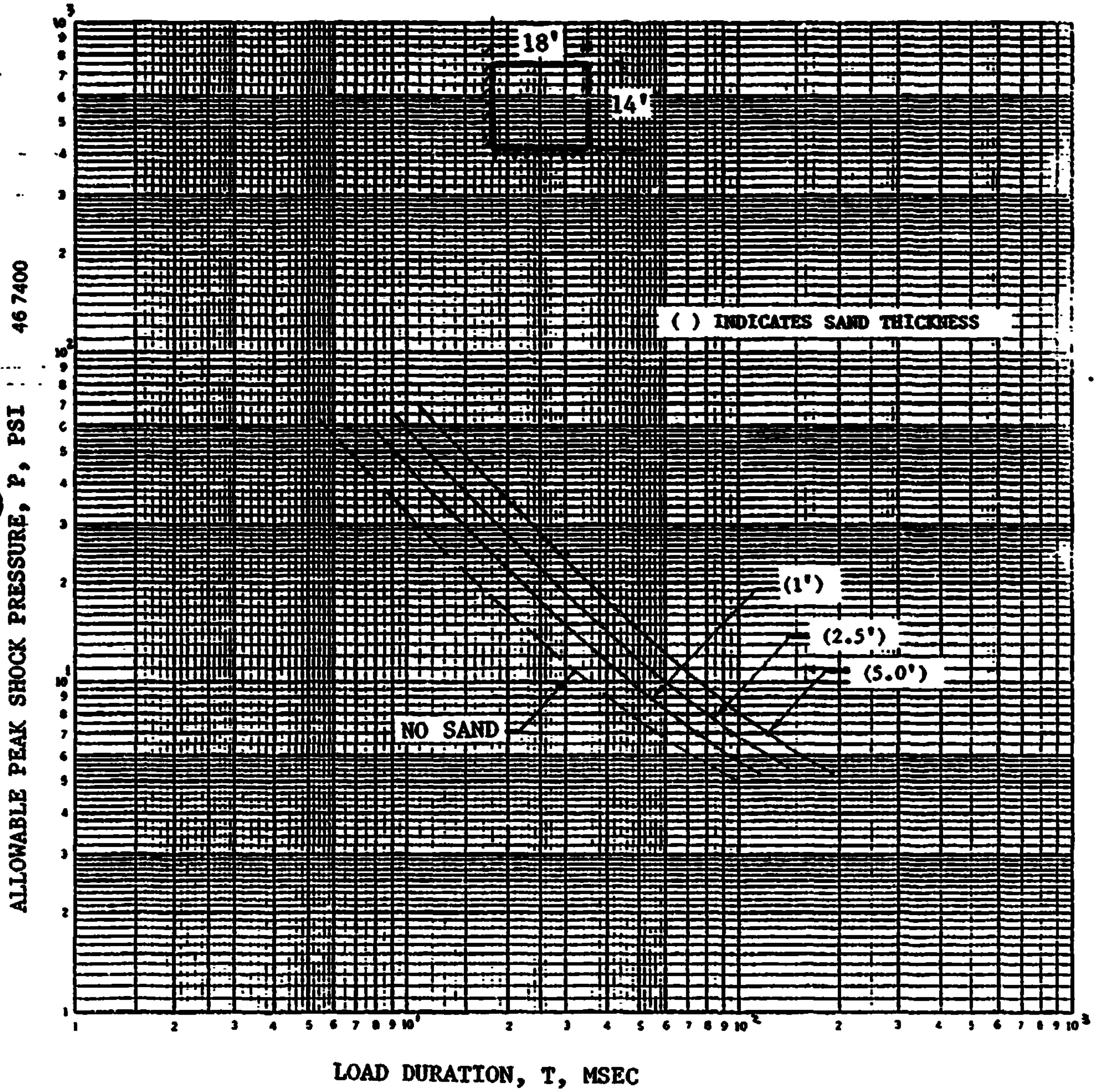
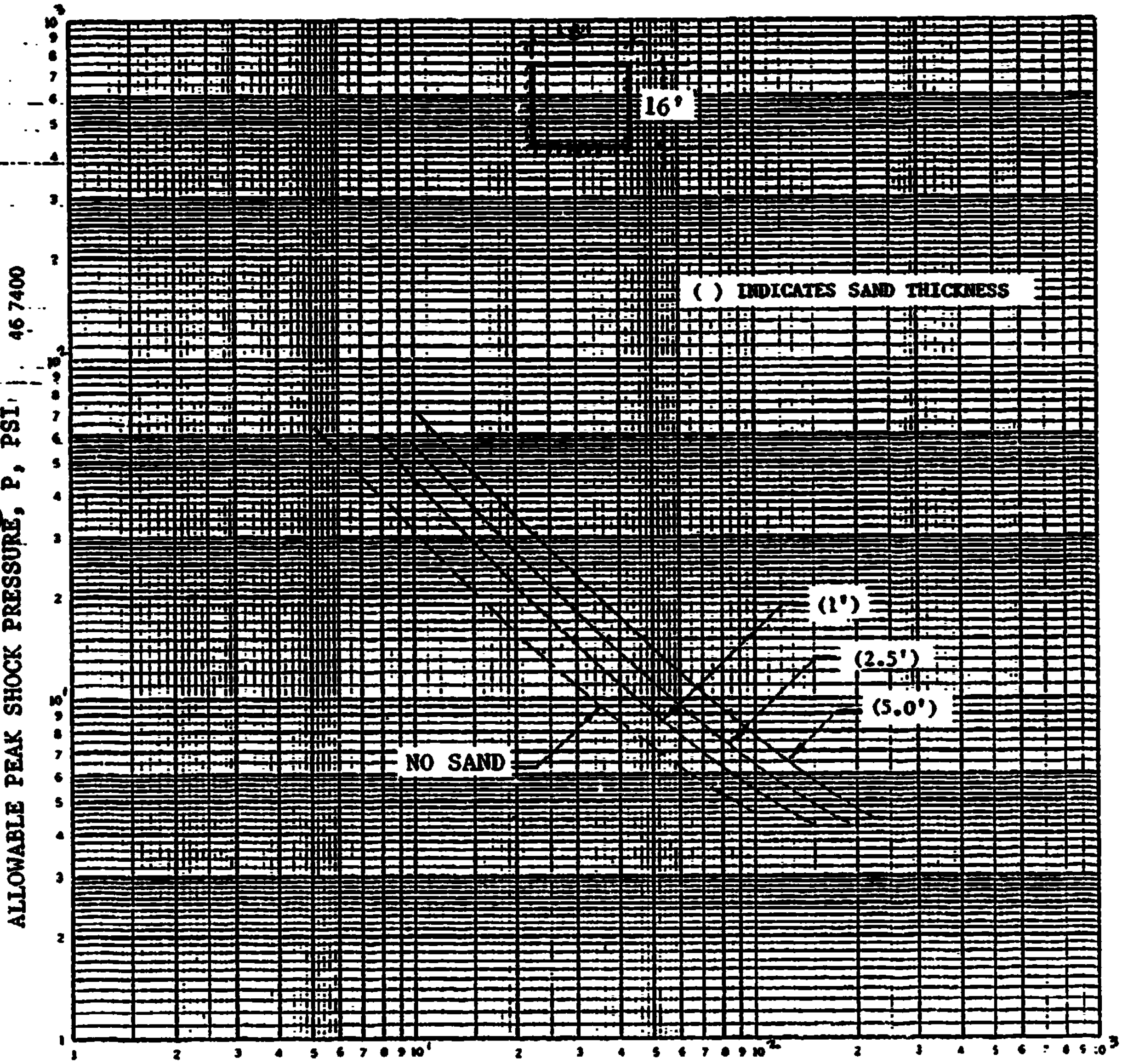


FIGURE 3-37 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION



LOAD DURATION, T, MSEC

FIGURE 3-38 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION

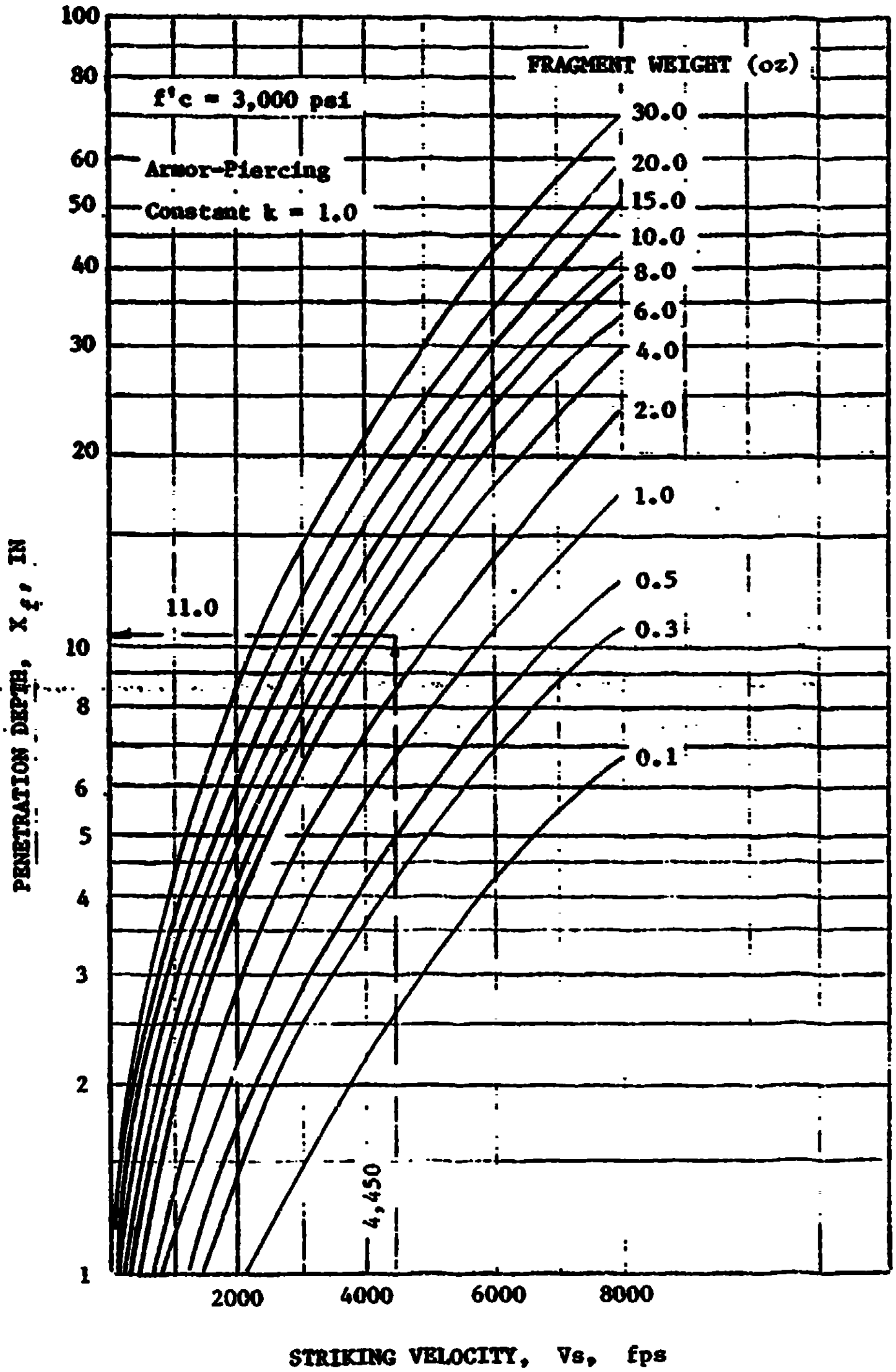


FIGURE 3-39 PENETRATION DEPTH VS STRIKING VELOCITY

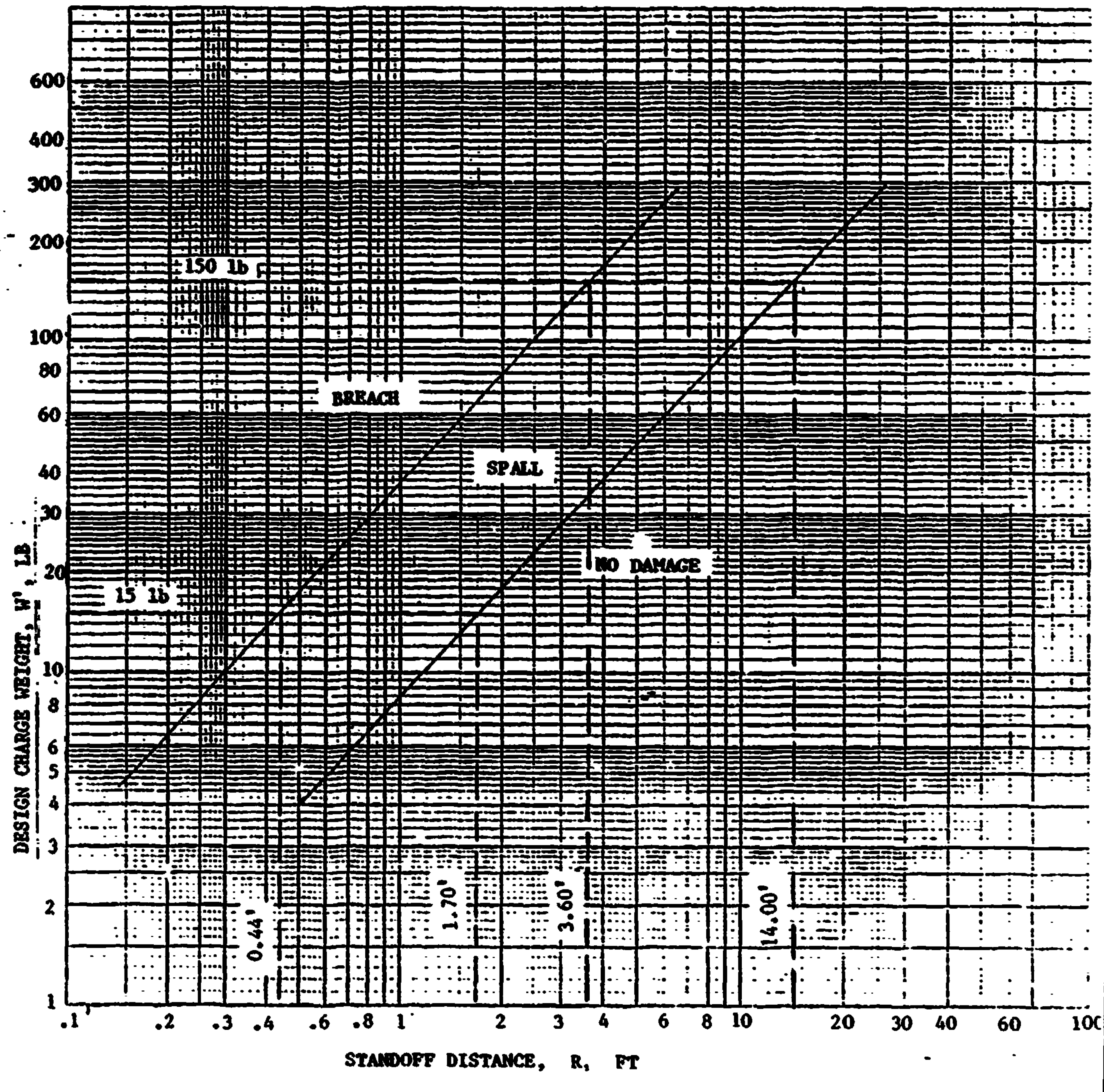


FIGURE 3-40 DESIGN CHARGE WEIGHT' VERSUS STANDOFF DISTANCE(BARE CHARGE)

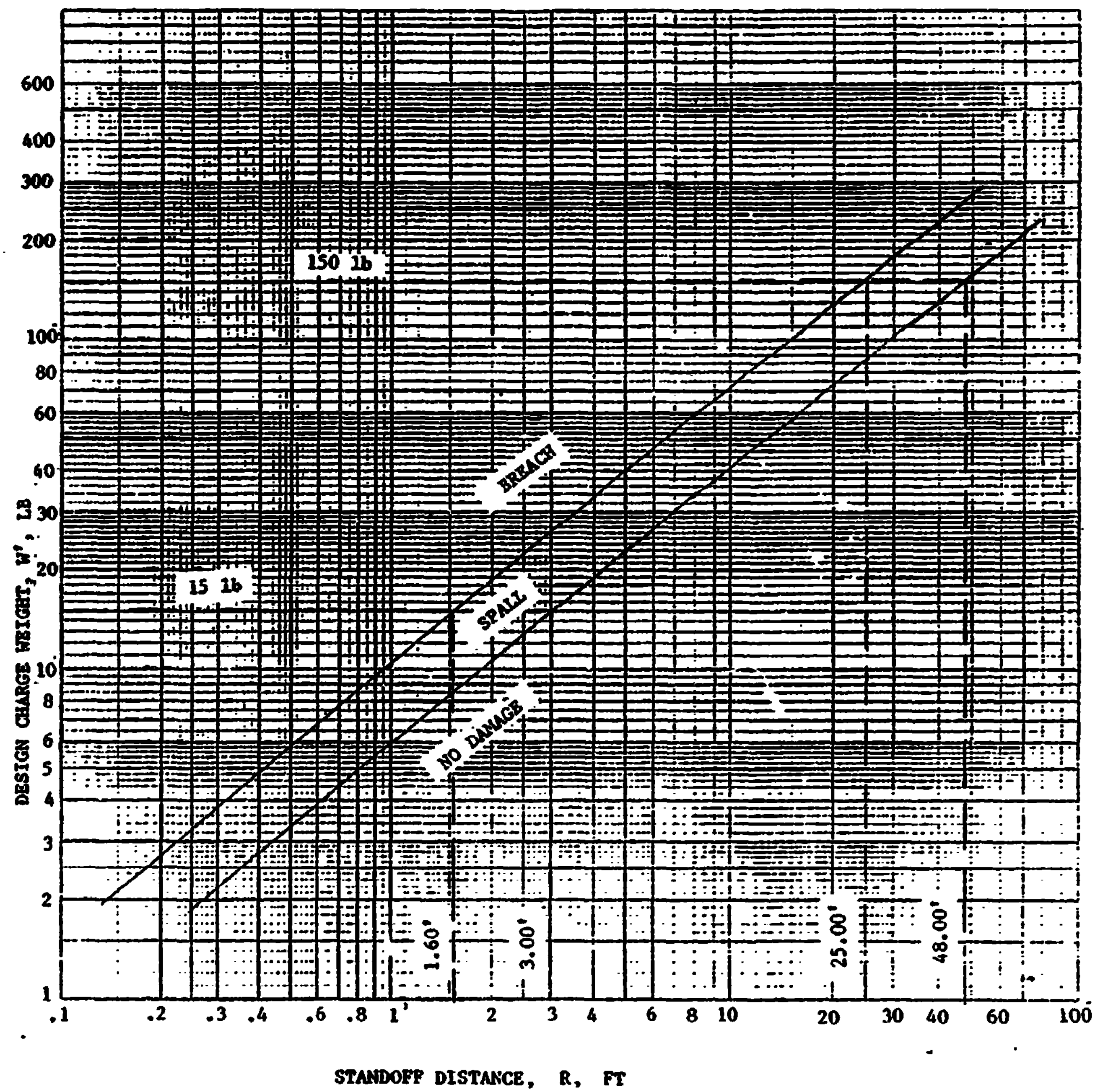


FIGURE 3-41 DESIGN CHARGE WEIGHT VERSUS STANDOFF DISTANCE (CASED CHARGES)

TABLE 3-1 DYNAMIC PROPERTIES OF 12-INCH CANTILEVER SDW

WALL SIZE FT.	ULTIMATE RESISTANCE PSI	STIFFNESS $LB./IN^3$	NATURAL PERIOD MSEC
10L X 10H	1.73	9.59	85.60
10L X 12H	1.21	4.63	123.26
10L X 14H	0.88	2.50	167.77
10L X 16H	0.68	1.46	219.12

L...Wall length
H...Wall height

TABLE 3-2 DYNAMIC PROPERTIES OF SUBSTANTIAL DIVIDING WALL FIXED TWO-SIDES

WALL SIZE FT.	ULTIMATE RESISTANCE PSI	STIFFNESS LB./IN^3	NATURAL FREQUENCY MSEC
10L X 10H	8.61	27.20	47.63
10L X 12H	7.22	21.39	54.15
10L X 14H	6.23	19.08	57.67
10L X 16H	5.61	17.33	60.84
12L X 10H	7.27	20.91	54.78
12L X 12H	5.98	13.12	68.58
12L X 14H	5.15	11.19	74.76
12L X 16H	4.53	9.52	81.49
14L X 10H	7.27	17.63	60.00
14L X 10H	5.19	10.48	77.28
14L X 14H	4.39	7.08	93.35
14L X 16H	3.86	6.11	101.07
16L X 10H	5.56	15.82	63.66
16L X 12H	4.57	8.92	84.25
16L X 14H	3.89	5.83	103.51
16L X 16H	3.36	4.15	121.92
18L X 10H	5.11	14.69	66.36
18L X 12H	4.08	8.02	89.22
18L X 14H	3.47	5.01	112.27
18L X 16H	3.02	3.50	133.47

W...Wall length
H...Wall height

TABLE 3-3 DYNAMIC PROPERTIES OF SUBSTANTIAL DIVIDING WALL FIXED THREE SIDES

WALL SIZE FT.	ULTIMATE RESISTANCE PSI	STIFFNESS LB/IN^3	NATURAL FREQUENCY MSEC
10L X 10H	20.86	211.77	18.11
10L X 12H	19.60	186.25	19.52
10L X 14H	18.59	166.87	20.77
10L X 16H	17.75	189.66	19.59
12L X 10H	16.37	110.74	24.75
12L X 12H	14.49	102.13	26.07
12L X 14H	13.74	91.63	27.78
12L X 16H	13.13	83.33	29.33
14L X 10H	13.40	63.97	32.20
14L X 12H	11.79	59.06	33.96
14L X 14H	10.64	55.13	35.49
14L X 16H	10.17	50.19	37.50
16L X 10H	11.27	39.87	40.28
16L X 12H	9.91	36.69	42.66
16L X 14H	8.90	34.32	44.61
16L X 16H	8.15	32.31	46.35
18L X 10H	9.67	27.35	48.04
18L X 12H	8.51	24.16	52.06
18L X 14H	7.64	22.54	54.58
18L X 16H	6.95	21.28	56.70

W...Wall length
H...Wall height

TABLE 3-4 FRAGMENT PENETRATION COMPARISON[1]

MATERIAL	PENETRATION DEPTH	REFERENCE
MILD STEEL PLATE	1.9"	TM5-1300 FIGURE 5-29
SAND	40.0"	TM5-1300 FIGURE 4-81
CONCRETE	X_f = 7.7"	SEE NOTE 3
	T_{tf} = 10.2"	TM5-1300 EQ. 4-204
	T_{sp} = 11.7"	TM5-1300 EQ. 4-207

(1) Based on 8-inch HE projectile design fragment.

a. Weight of fragment = 3.44 oz

b. Striking velocity = 4,450 feet/second

c. X_f = (Constant k)(X_f from Figure 3-39)   k=0.70 for mild steel
   = (0.70)(11.0) = 7.7"

4.0 BLAST PRESSURE PREDICTION

4.1 GENERAL

During the study it became apparent that the development of a useful guide must be based on simplified methods in predicting the blast loading. Installation personnel must not be burdened with tedious complicated procedures in estimating the blast loading required for analyzing existing facilities with SDWs. These installations do not have the necessary software to accomplish such a task, neither it is expected that they perform such a complicated engineering function. The approach then, was arriving at a method to reasonably predict the blast effects at a specified standoff.

4.2 BLAST EFFECTS IN MULTIPLE BAYS

Facilities with Substantial Dividing Walls can, for the most part, be classified as building with multiple bays. Generally, the building footprint includes a common corridor between the cubicle bays and the building exterior.

Most building exteriors, including the roofs, are of lightweight material that can be classified as "frangible" elements. Recent studies have shown that blast wave reflection occurring even with the lightest frangible material. A blast wave from an explosion in a donor bay will reflect and diffract around the corners and into adjacent bays. Prediction of loadings on the structural elements in a donor bay is usually possible. In fact the draft TM5-1300 provides adequate data to predict the blast loadings. However, procedures for predicting initial or reflected shock wave loading in corridors of structures having such complex geometry is not presently available.

4.3 BLAST LOADING PREDICTION

As previously addressed, methods to predict blast loadings in multiple bay facilities is not presently available. In development of this guide, several procedures in evaluating blast effects were considered. These methods ranged from blast loads in tunnels to methods described in TM5-1300. It was concluded, upon review of these methods, that blast effects at a standoff from a donor bay can best be predicted, to reasonable accuracy, using the computer program "SHOCK" reference f. The greatest challenge was the prediction of the blast loads from the reflective surfaces in a cubicle bay assuming no accessability to computer softwares. After a significant computer runs using "SHOCK" were made, the following were noted:

a. The incident wave shock pressure and scaled shock impulse on the blast surface in question is obtained from TM5-1300, Figure 2-7 (Shock Wave Parameters in free air).

b. The shock pressure and scaled shock impulse from the reflective surfaces is approximately of the same order of magnitude as the incident wave scaled shock impulse.

c. The shock pressure from the reflective surfaces is also of the same order of magnitude as the incident pressure.

d. The maximum average shock pressure on the element in question is the largest of all pressure values.

e. The total scaled impulse is the sum of the reflecting surfaces values and the incident wave value.

f. The impulse duration on the blast surface is calculated using the traditional formula, $T = (2)(i_r/W^{1/3})/P_r$

The preceding suggests that a reasonable total impulse from all reflective surfaces would be the incident wave impulse of the element in question multiplied by the total number of reflective surfaces. This total reflective impulse when added to the incident wave impulse of the element in question, would result in a reasonable value for design.

From the preceding it became apparent that multipliers (pressure and impulse coefficient) may be necessary to more accurately duplicate the results of blast loadings obtained from the program "SHOCK". To determine these multipliers, several "SHOCK" runs were made in which the net explosive weight and the wall size were varied. The results were reduced to the data points presented in Figures 4-1 and 4-2. Shown in these figures are the multipliers required to bring the predicted pressures and impulses to those obtained from the program "SHOCK". The data points were enveloped by an upper and lower bound curves. Using the upper bound curve would be too conservative since the attenuation effects from the intervening walls have not been considered. A method to reasonably estimate the blast effects of intervening wall effects is presently not available. Therefore, using a mean curve would be most appropriate for usage in the development of the guide.

Based on the preceding, the following method will therefore be used in predicting the pressure and duration on the cubicle wall in question:

a. Determine the Scaled distance, $Z=R/W^{1/3}$, to the element in question.

b. Determine the reflective pressure (p_r), and scaled impulse ($i_r/W^{1/3}$) from Figure 4-3.

c. Determine total scaled impulse $i_r/W^{1/3} = i_r/W^{1/3} + (4)(i_r/W^{1/3})$.

d. Read from Figures 4-1 and 4-2 the reflection pressure and impulse coefficients respectively.

e. Multiply the reflective pressure from step b above by the pressure coefficient from step c.

f. Multiply the total scaled impulse from step c above by the impulse coefficient from step c.

g. Multiply the predicted scaled impulse from step e above by $W^{1/3}$ to determine the predicted impulse (i_r).

h. Calculate load duration, $T=2i_r/p_r$.

i. Design parameters: Pressure... from step e.
Load Duration ... from step h.

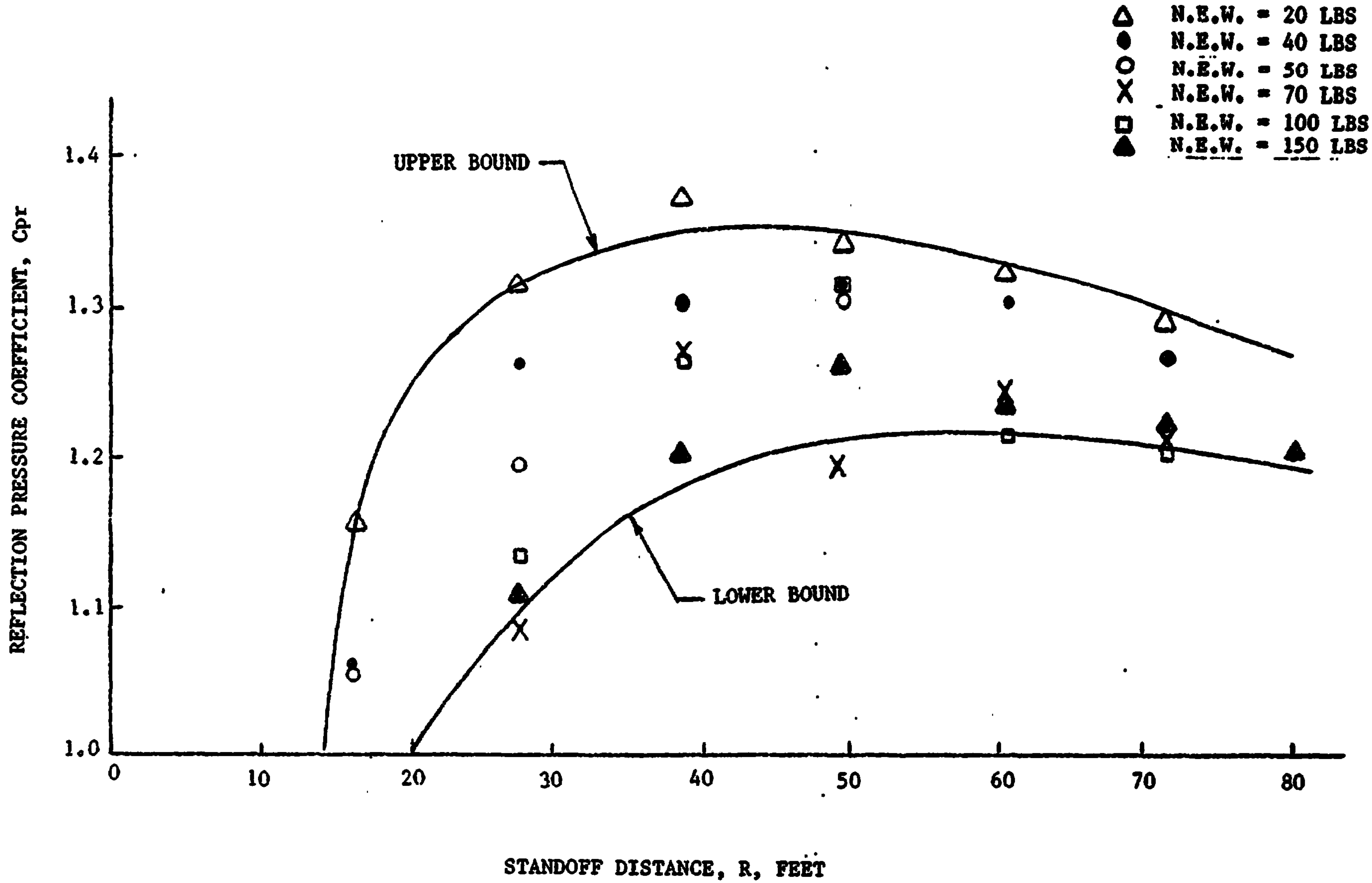


Figure 4-1 REFLECTION PRESSURE COEFFICIENT vs STANDOFF DISTANCE

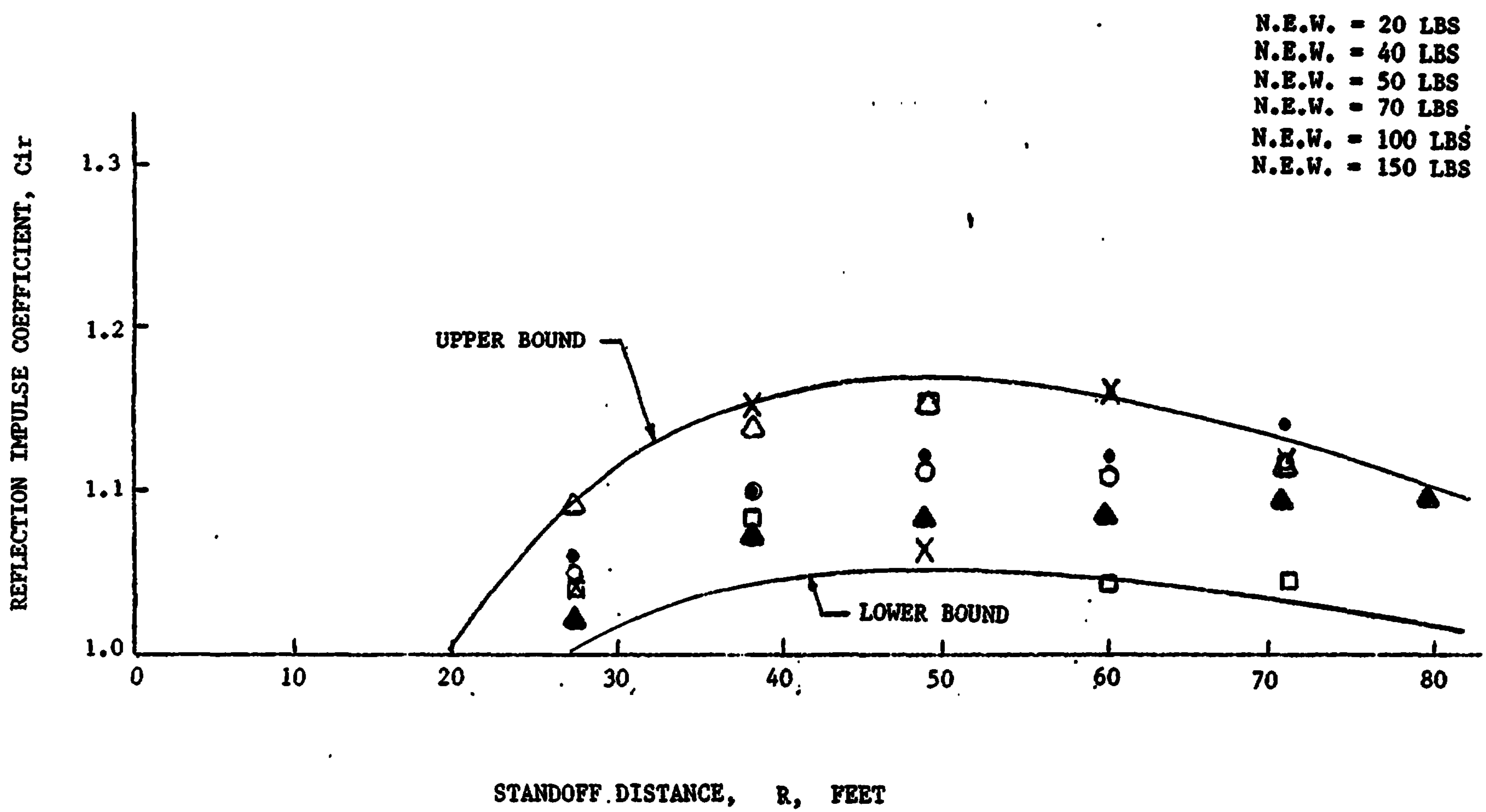


Figure 4-2 REFLECTION IMPULSE COEFFICIENT vs STANDOFF DISTANCE

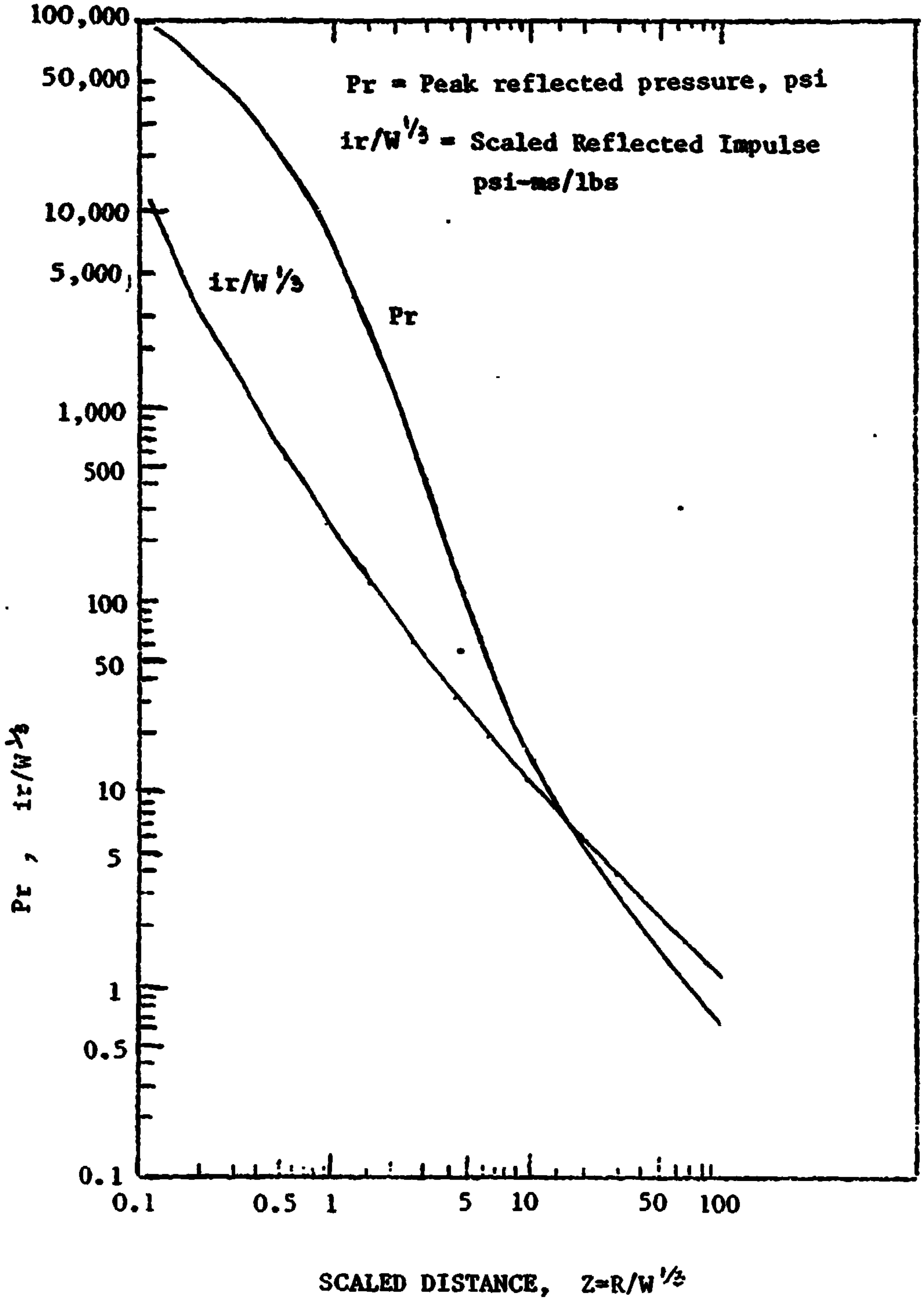


Figure 4-3 SHOCK WAVE PARAMETERS

5.0 MISCELLANEOUS

5.1 STRENGTHENING OF SDWs FOR INCREASED BLAST RESISTANCE

Methods to stregthen SWD for increased blast resistance were considered. Two feasible alternates are suggested in Volume I of this guide. The proposed concepts ,if used, will allow positioning operators closer to the remotely controlled donor bay. Implementation of these concepts must receive approval by DDESB staff elements, and must be designed by qualified engineers. Design verification and detailing must also include analysis of all structural elements protecting the operators, such as roof and wall elements. Since most SDW bay are open to a common corridor, the spillover pressure around the front must be determined to ensure personnel are not exposed to pressures in excess of 2.3 psi.

In Volume I strengthening of walls is discussed. Strengthening of roofs is more complex due to the different types of roofs that may be exist on the installations. Older facilities have been constructed of corrugated cement asbestos roofing. These types of roofs are expected to fail at about 6 psi overpressure, reference g. For the higher quantities of explosive these roofs may not be adequate to resist the spillover pressures. One method to strengthen to roofs is by upgrading using properly designed steel deck to resist the blast loadings.

5.2 PORTABLE SHELTERS

Portable shelters are one method in protecting operators when the safety requuirements has been exceeded. At the present, standard portable shelters are not in the inventory. Shelters designed for a specific blast loading conditions have been designed and used on some Army munition facilities. Mississipi AAP and Kansas AAP have used fixed-in-place shelters to protect operators during the performance of hazardous operations. These to our knowledge were for small quabtities of explosives. The bottom line is, the feasibility in using portable shelters must be on case-by-case basis and designed to a predetermined set of blast loads.

5.3 OPERATOR PROTECTION FROM HIGH ANGLE FRAGMENTS

During a remote operation, personnel must be protected from spillover pressure as well as fragments. The low angle high velocity fragments are resisted by intervening SDWs located between the operator and the donor bay. On the other hand, the high angle low velocity fragments must be resisted by the structural system over the occupied bay. Most roofing systems exisiting on Army munition facilities, provides acceptable levels of protection to occupants from high angle fragments. This is predicated on roof survivability from spillover pressure. When overpressures on the roof exceeds its load carrying capacity, the common method for protection has been the use of expanded metal lath positioned under the roof structural support system to prevent hazardous debris from striking the occupants. An alternate system would be the use of a "Geogrid" system. Refer to Volume I for details. This system is better suited for upgrading existing facilities due to ease of installations and cost benefits. Actual application of these systems must be engineered by experienced designers, and must receive proper approval by DDESB elements.